Performance in Simulation

Outline • Goal • Simulation setup • Verification • Performance • in R&D

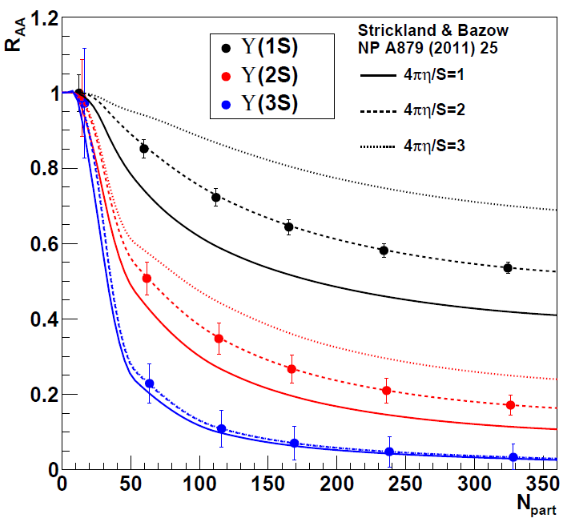
Jin Huang (BNL)

PHENIX

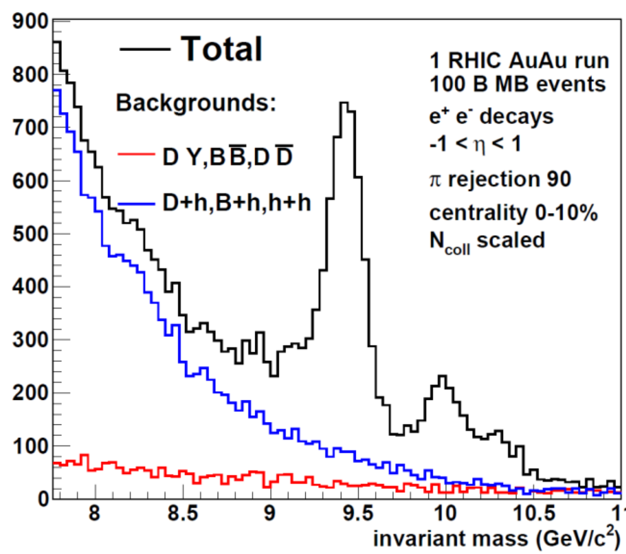
Quick recap: sPHENIX EMCal

1. Upsilon electron ID & Triggering – main driving factor
2. Direct photon ID
3. Part of jet energy determination
4. Heavy flavor electron ID

Upsilon R_{AA}

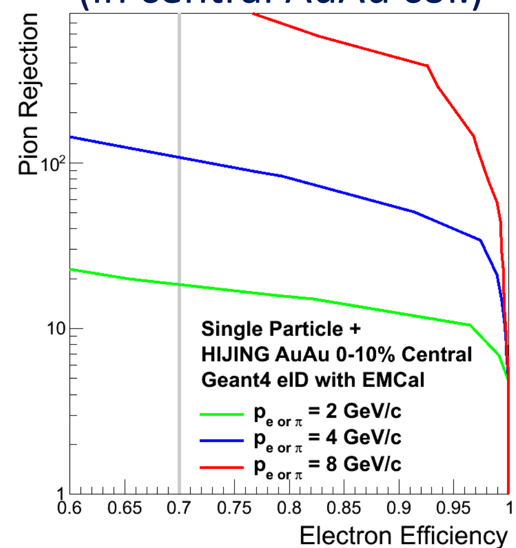


Hadron VS Upsilon



Hadron Rej. ~100:1

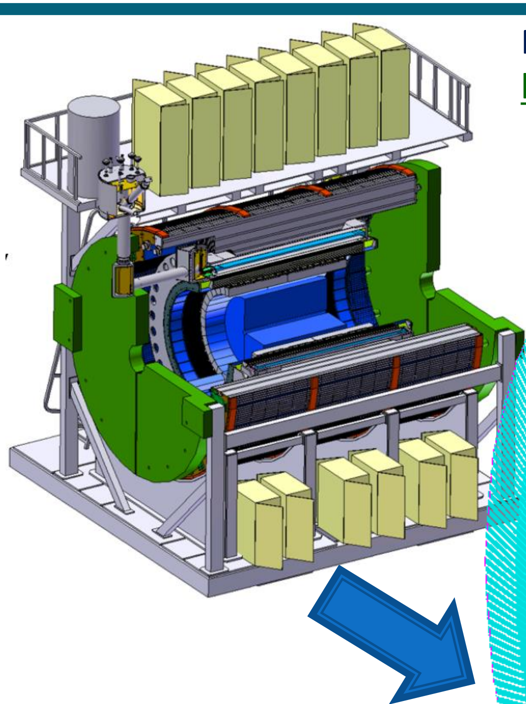
(in central AuAu col.)

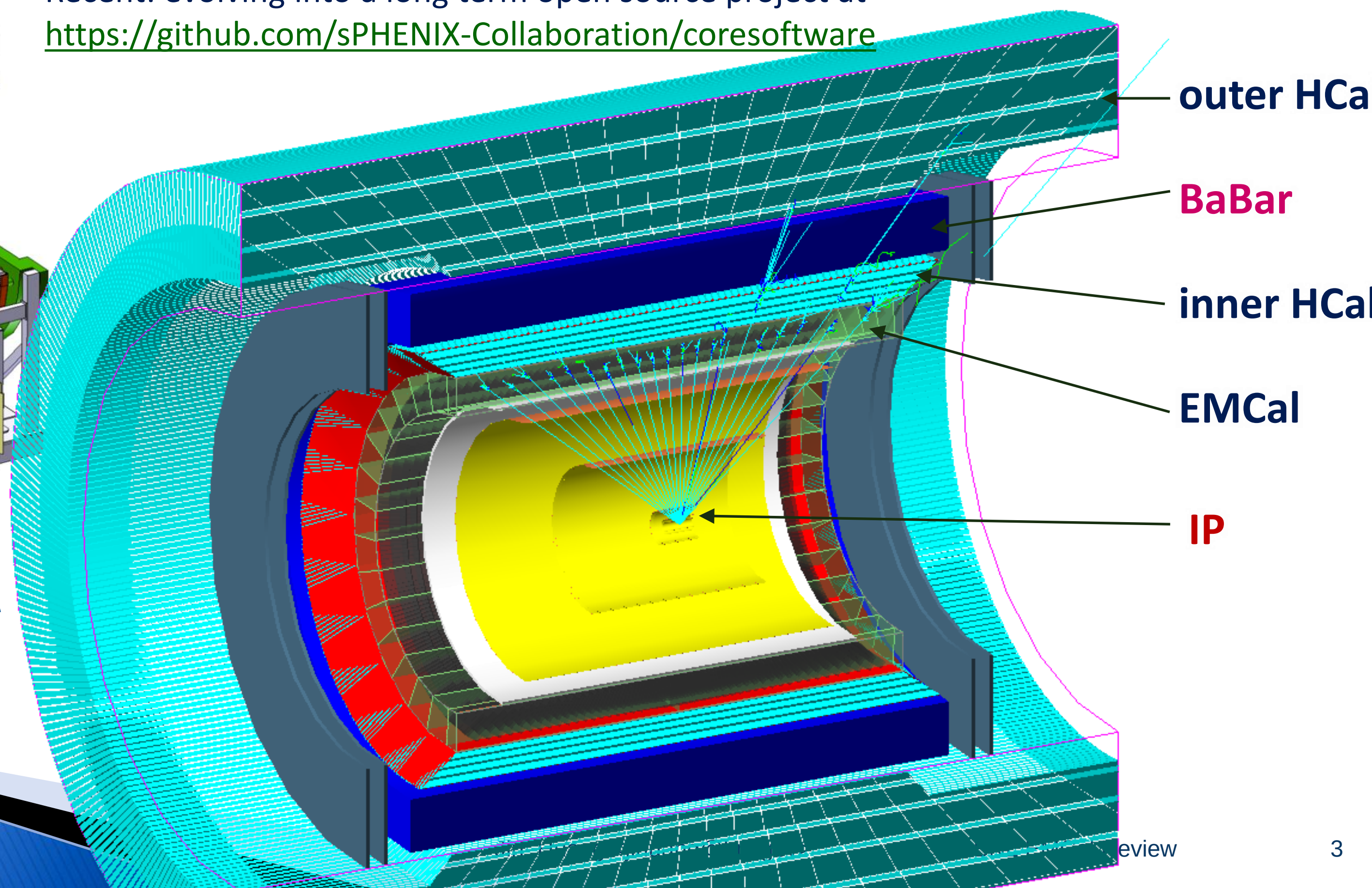


sPHENIX in Geant4

- EM calorimeter (EMCal) : 18 X_0 SPACAL
- Inner hadron calorimeter (inner HCal) : 1 λ_0 SS-Scint. sampling
- BaBar coil and cryostat. (BaBar): 1.4 X_0 , B0 ~ 1.5 Tesla
- Outer hadron calorimeter (outer HCal) : 4 λ_0 SS-Scint. sampling

Recent: evolving into a long term open source project at
https://github.com/sPHENIX-Collaboration/coresoftware





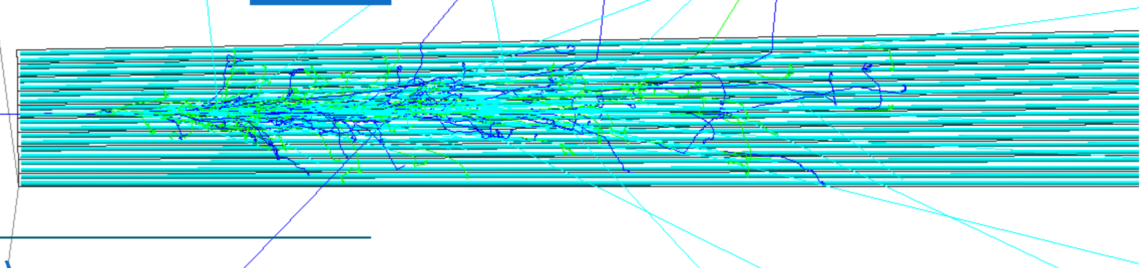
SPACAL in Geant4

- Tungsten + Epoxy material: 12.18 * g / cm3, 96.9% mass with W (absorber only)
- Fiber: ϕ440um core (Polystyrene) + 15um skin (PMMA)
  - Thanks to the reference model from A. Kiselev (EIC Generic RD1)
- Fiber matrix is layout in triangle pattern with a nominal separation of 1mm
  20% (Vol.) in fiber → overall density with fiber ~ 10 g/cm^3
- Simulate all 10M fibers in detail for each event!

1-D tapered module
(as in 2014 test beam)

10GeV, e+

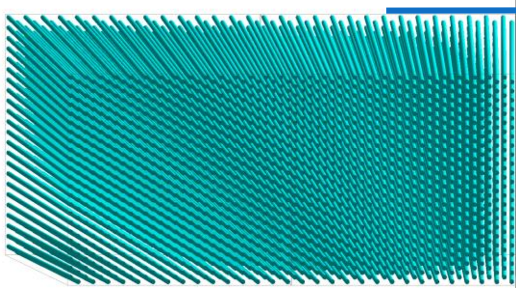
Side view 2 cm



2D tapered module (in R&D)

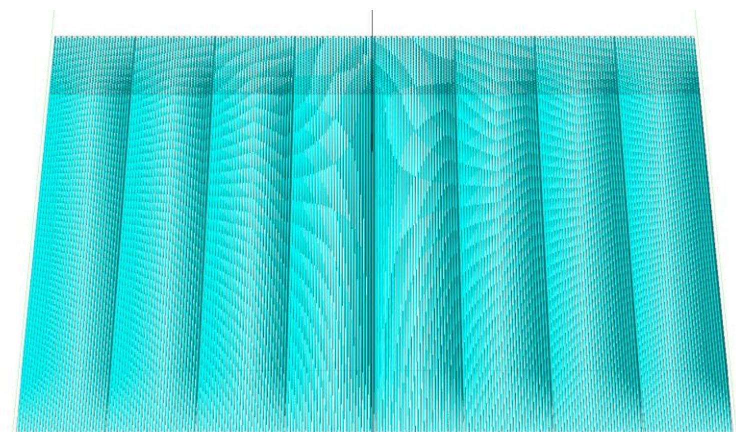
Particle view (2x1 modules)

2 cm



Side view (8x1 modules)

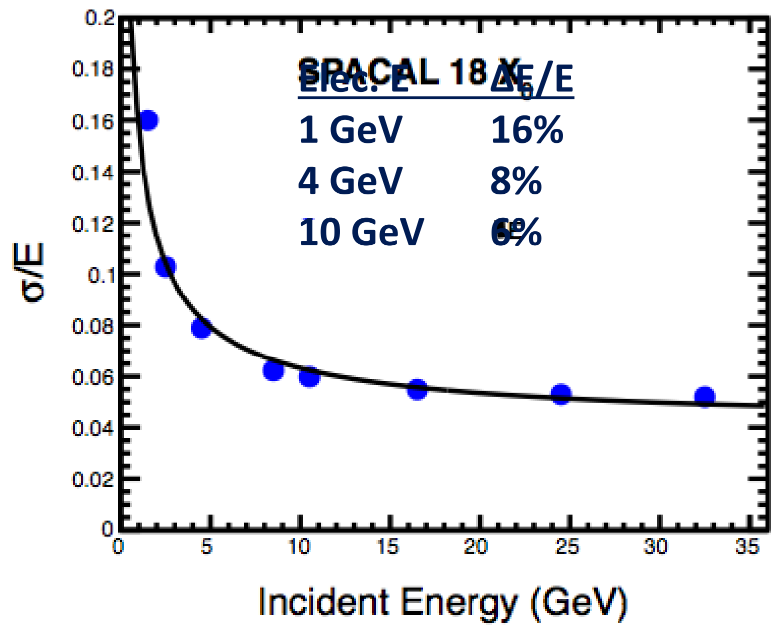
2 cm



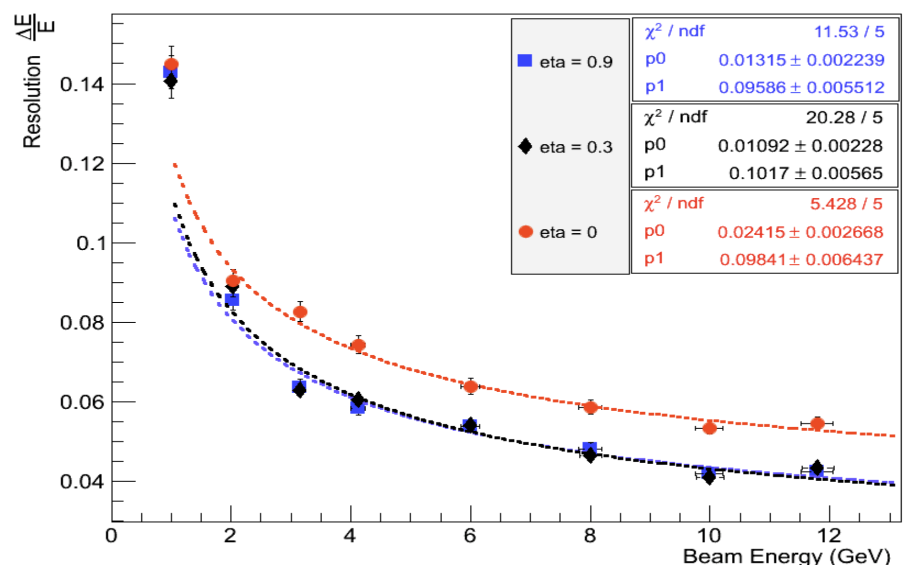
SPACAL verification (1): electron resolution

- Electron resolution → Electron PID efficiency
- Compared to simulation from EIC RD1 collaboration and beam test
- Consistent in general; more work needed on noise and cell structure simulation

sPHENIX simulation
5MeV(scint.)/tower zero-suppression



EIC RD1 study
FermiLab beam tests



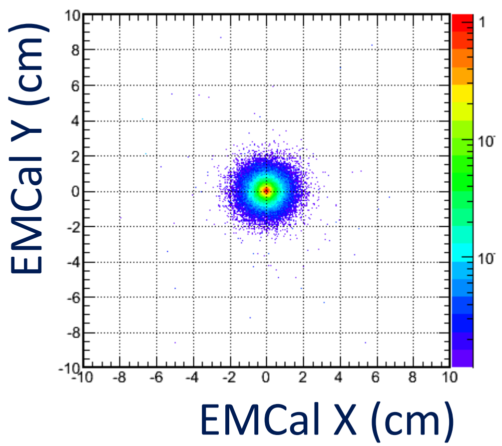
Courtesy: A.Kiselev (BNL)
DIS2014

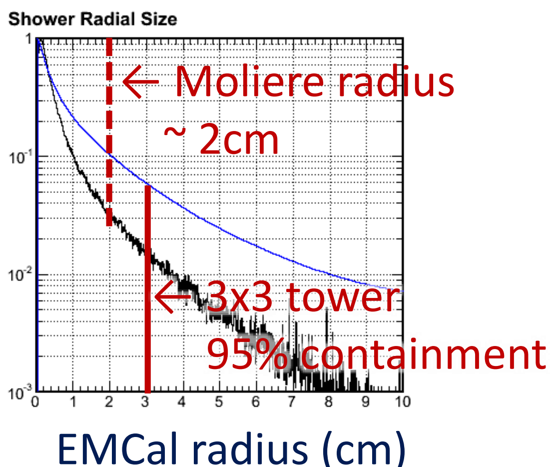
SPACAL verification (2): spatial response

- Spacial containment of showers → size of cluster

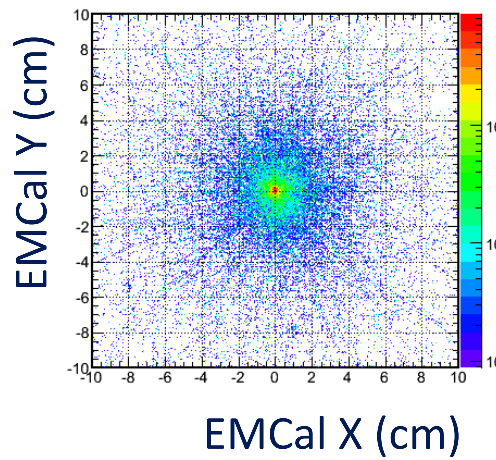
- Energy deposition (A.U.)
- Percentage outside radius

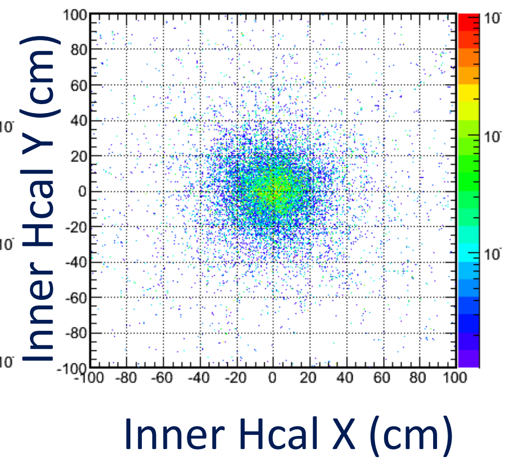
4 GeV Electrons

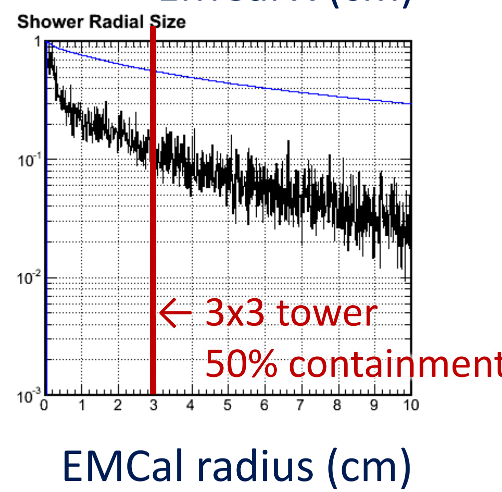


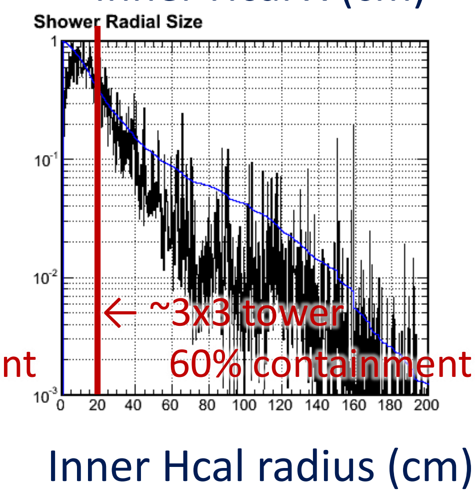


4 GeV Pions, that **passed E/p electron-ID cut**





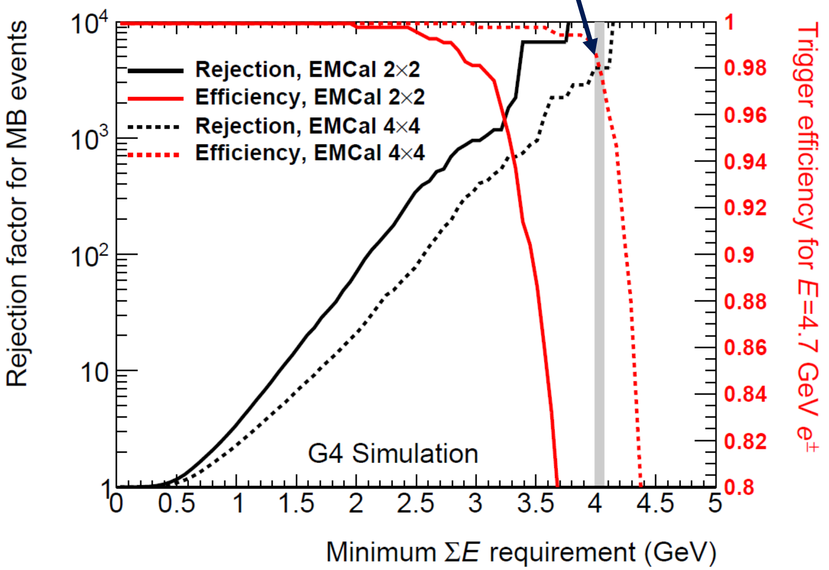




Triggering

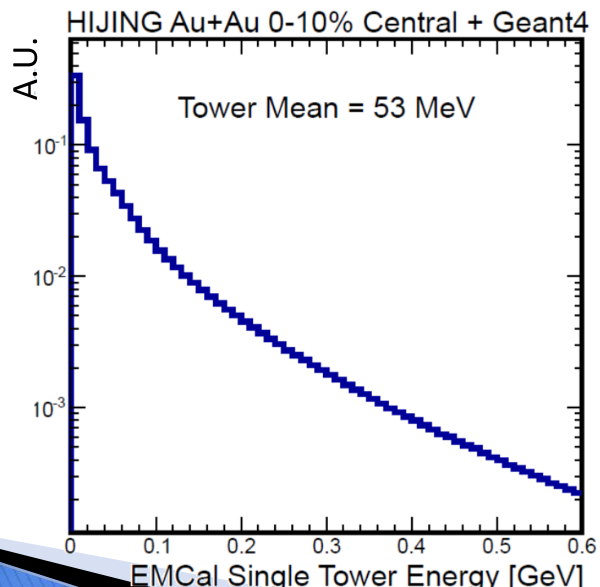
- sPHENIX intent to record all MB event in Au+Au collisions, taking advantage of 15kHz DAQ infrastructure at PHENIX
- p+p and p+A collisions will be delivered at higher collision rate
- EMCal tower-sum triggers are studied to select ϒ-events in p+p and p+A collisions
- Good efficiency and rejection were demonstrated in full event Geant4 simulations

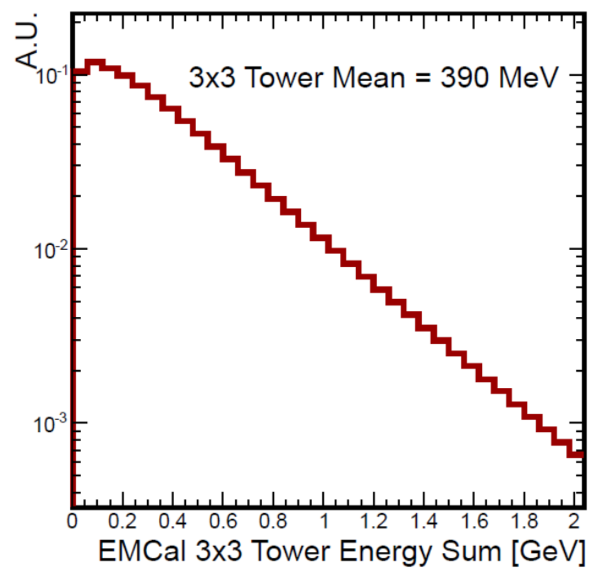
In √s=200 GeV p+p collisions
Expected EMCal 4x4 trigger threshold



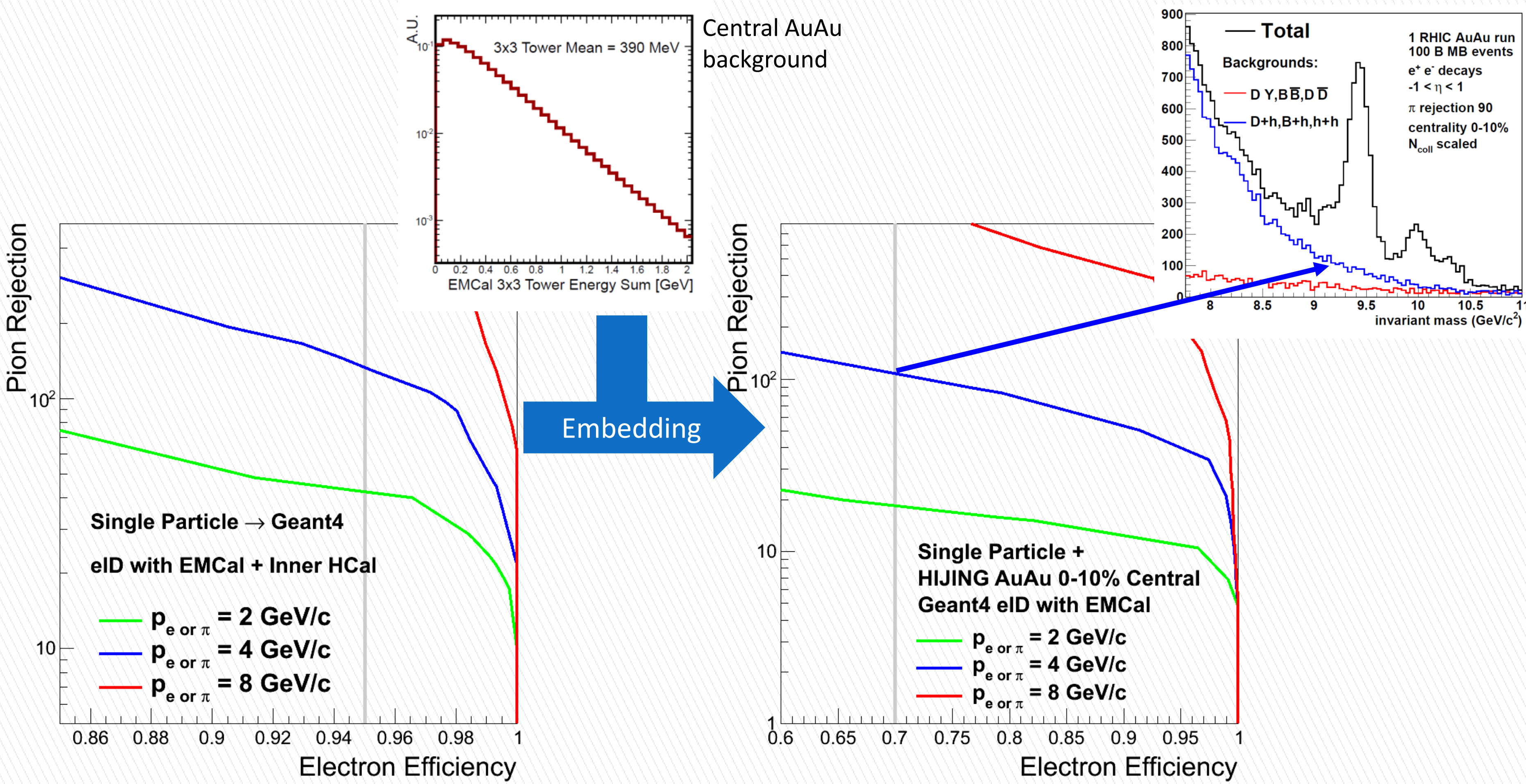
Event background distribution in Central AuAu

- Study of electron ID in central AuAu
  1. Embed single particle simulation to full event Hijing simulations (0-4.4 fm, ~0-10% Central, in full magnetic field)
  2. Get rejection through re-optimized EMCal+ HCal cuts
- EMCal background is moderate
  - Most hadron particle leave MIP energy in EMCal
  - Tight EMCal Moliere radius
- Inner HCal background is significant, render it less useful in electron ID (compared with an alternative tighter E/p cut from EMCal)





Compile everything together for electron ID



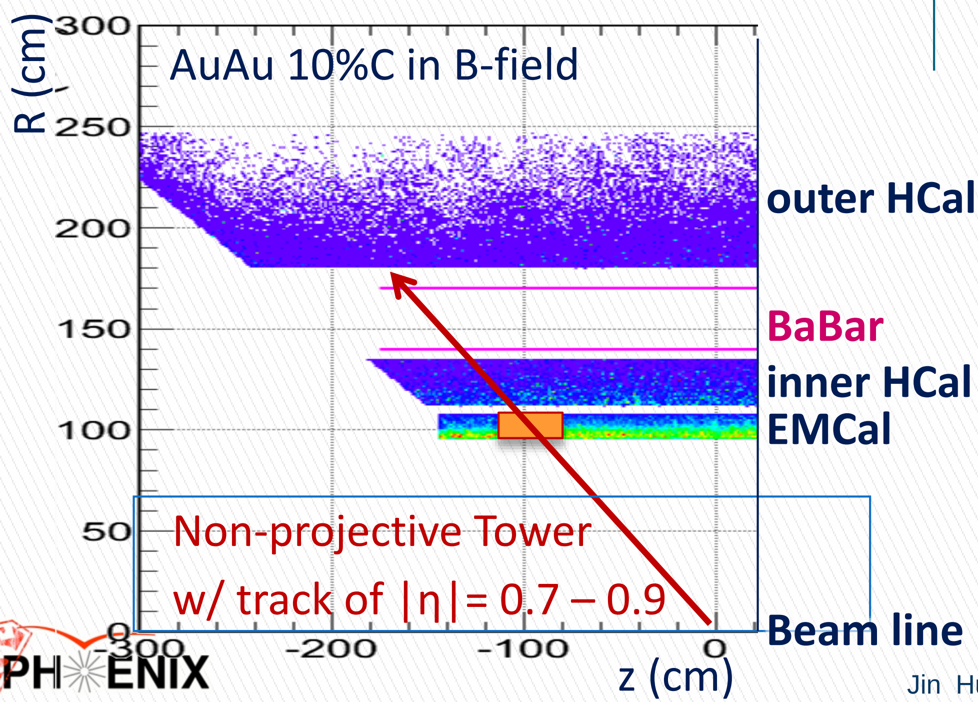
pp electron ID (EMC+HCAL)

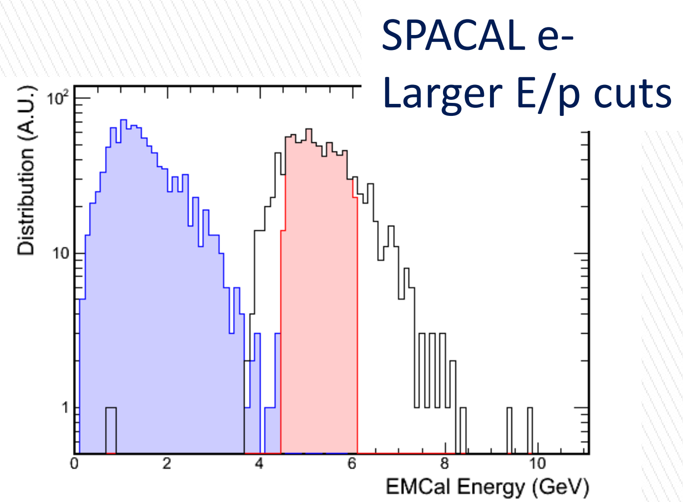
Central AA electron ID (EMC Only)

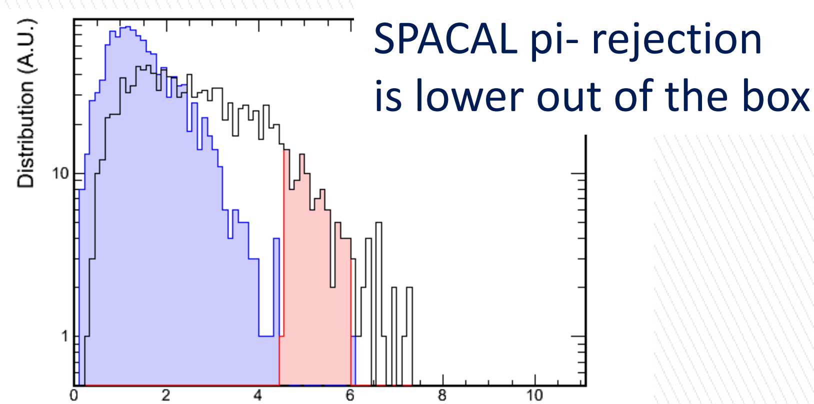
Larger pseudo-rapidity in central AuAu : under study

- Out of the box: larger |η|→ larger background
  - Longer path length in calorimeter
  - Covers more non-projective towers
- to improve (applied to the next slides)
  - Better estimate of the underlying background event-by-event (improve x1.5)
  - Use (radially) thinner ECal (improve x2)
- Possibilities for projective towers?

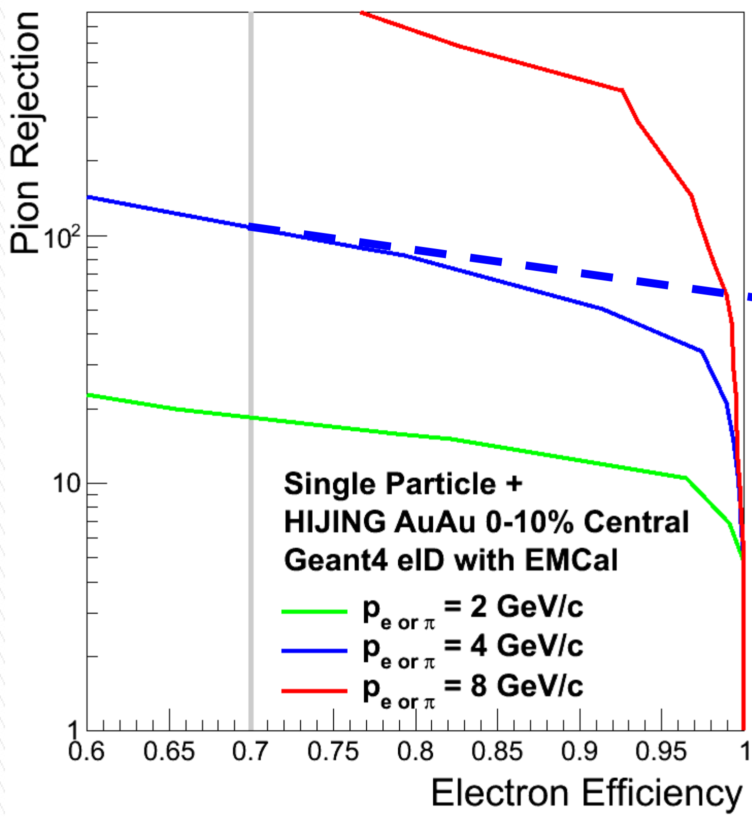
- all events (w/ embedding)
- with EMCal E/p cut (w/ embedding)
- Hijing background (AuAu 10%C in B-field)

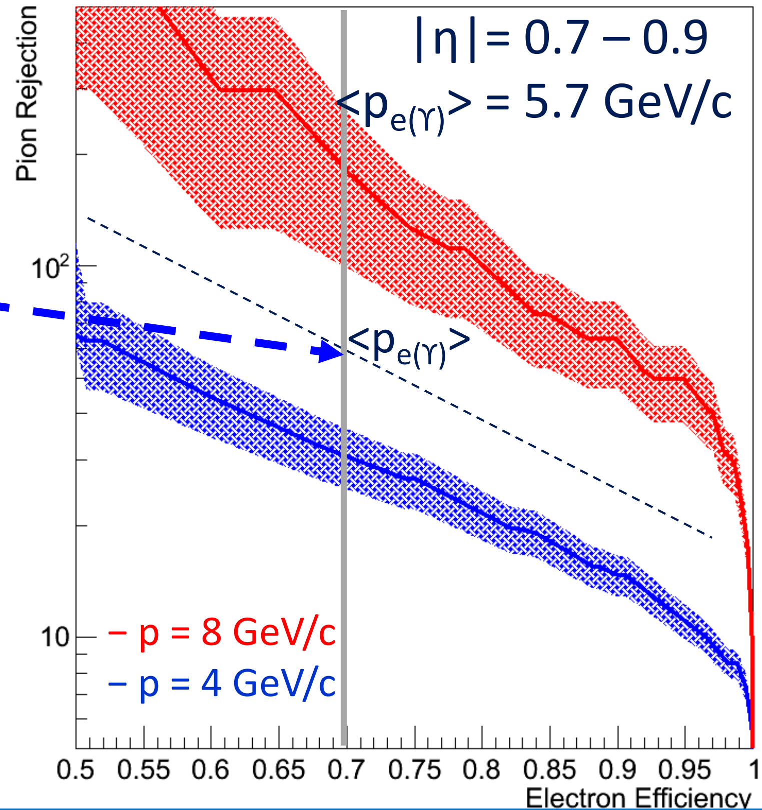






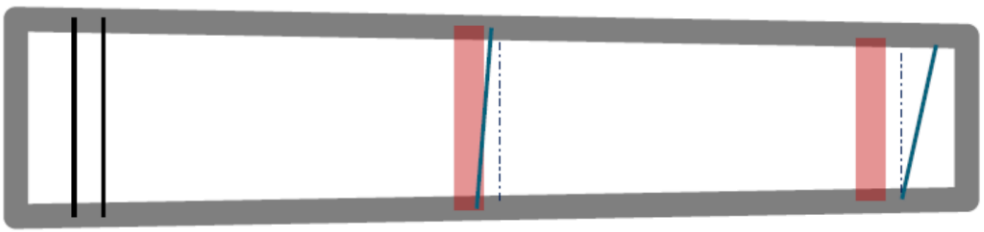
Quantitative comparison for EID performance in Geant4 (group hits to simulate for towers)





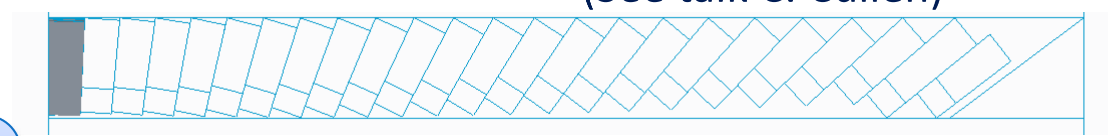
Central rapidity, |η|< 0.2 **Effectively projective** in polar direction	Forward rapidity, |η|= 0.7 – 0.9 **non-projective** in polar direction

On-going: first full projective SPACAL
Realistic considerations to simulation



2D tapered module R&D (See talk S. Stoll)

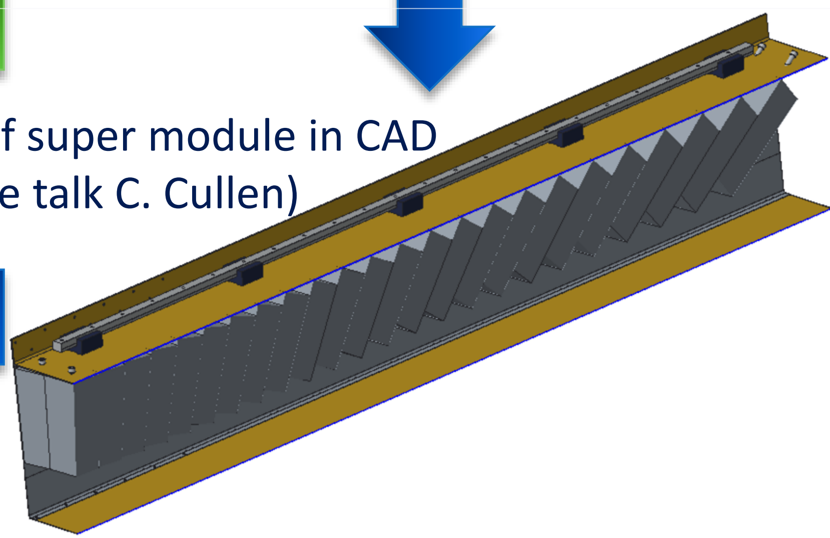
Fully projective SPACAL
(See talk C. Cullen)



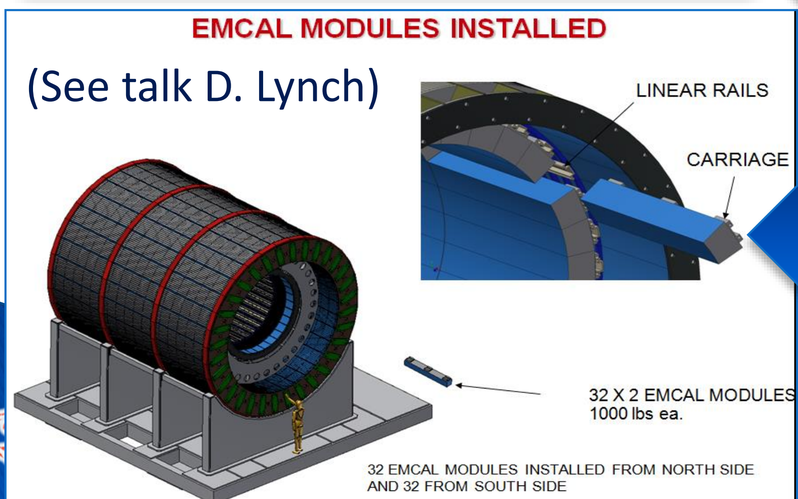
Simulation for 2-D projective EMCal: importing the CAD geometry into sPHENIX Geant4

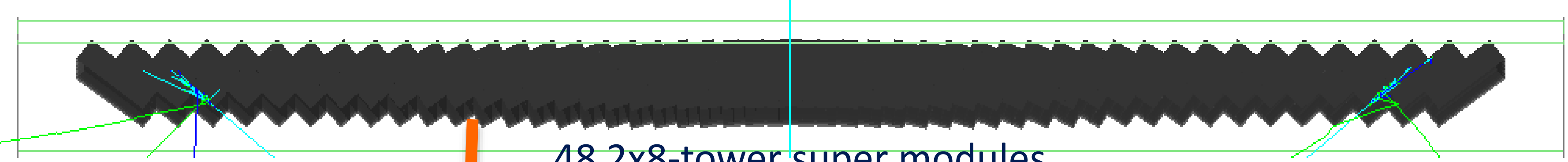
End July

Half super module in CAD
(See talk C. Cullen)



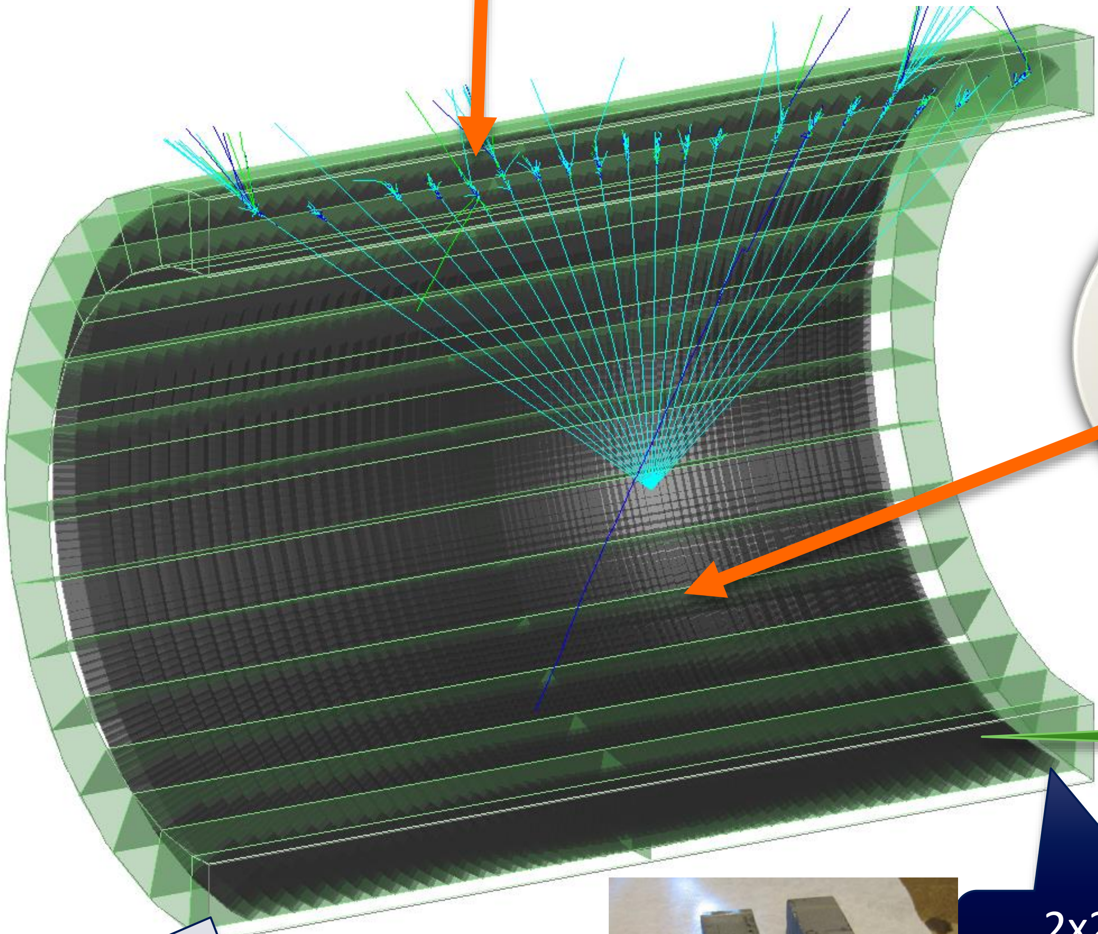
(See talk D. Lynch)

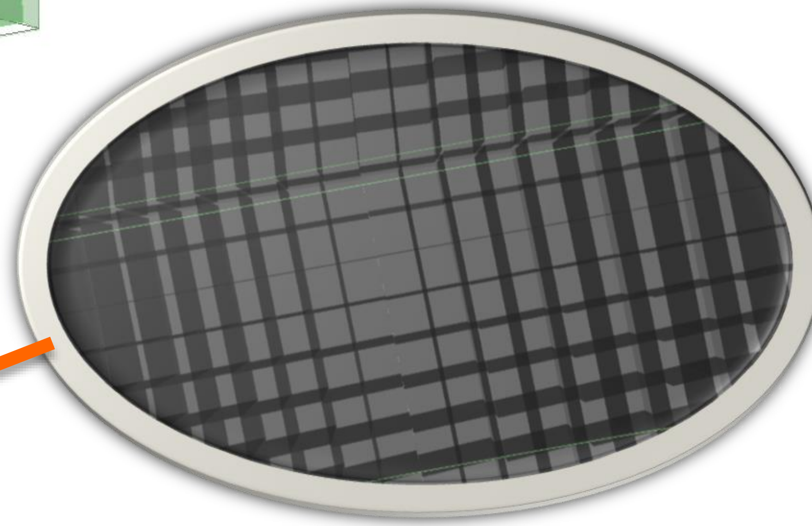




48 2x8-tower super modules

Towers project towards IP





Stainless steel SS310
Support box

2x2 2D tapered
SPACAL modules

Gap between modules are also implemented

- 300um tolerance outside super modules skins
- ~2mil between SPACAL and SS skin
- ~2mil between SPACAL modules

Happening now:

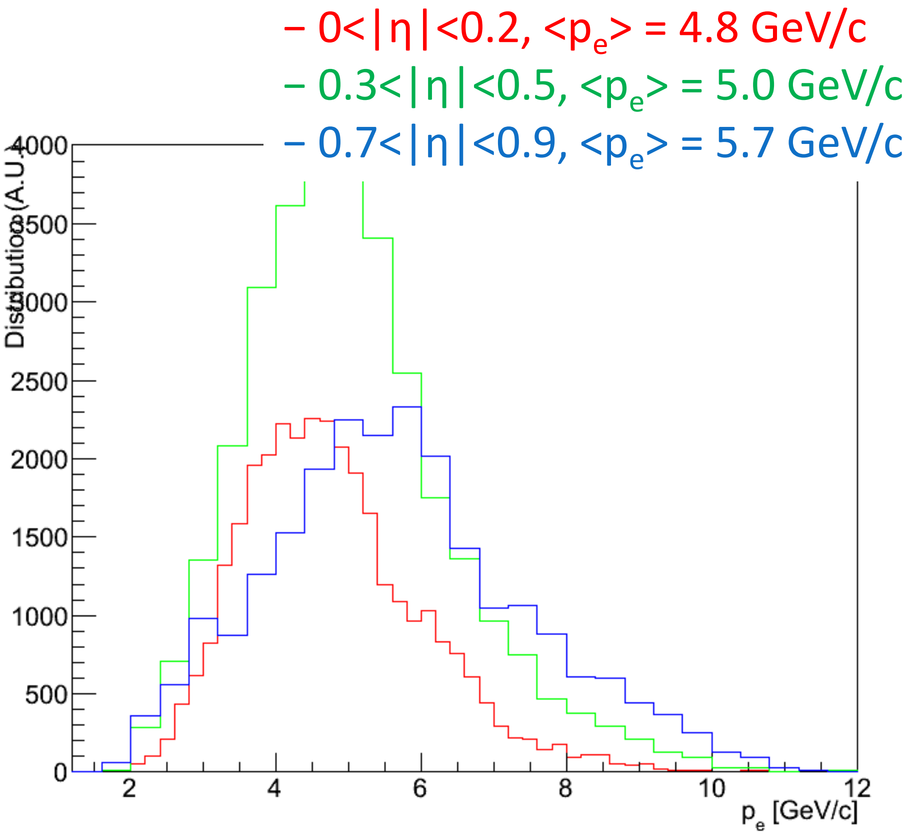
In performance re-evaluation

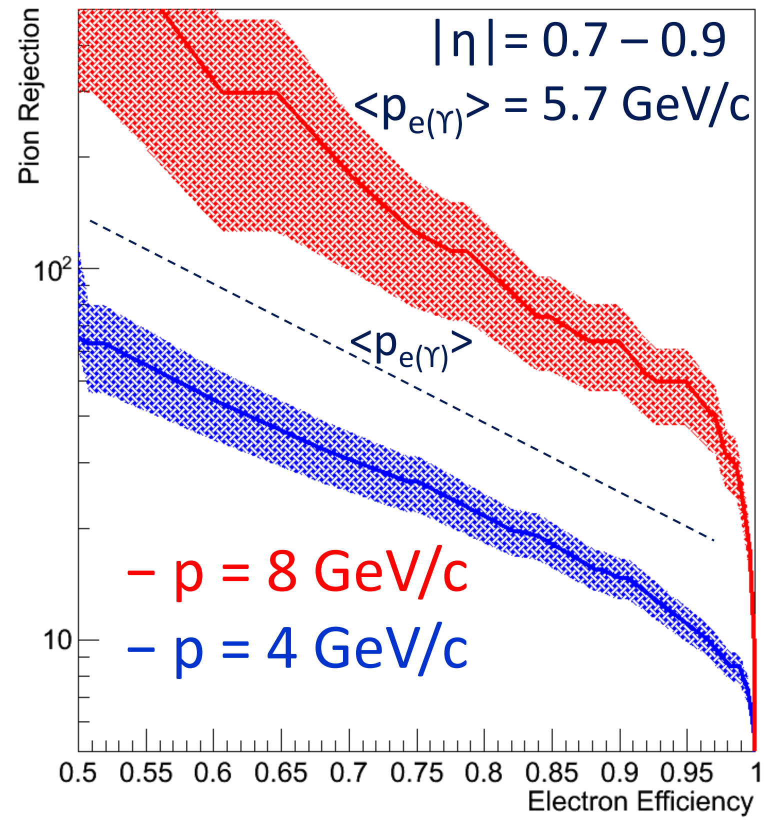
Summary

- sPHENIX detector has been implemented in Geant4
  - Including detailed simulation of SPACAL as EMCal
  - In general consistent performance with respect to the test beam
- First study showed reference EMCal design satisfying the requirement for the Upsilon trigger/electron ID requirement (main driving factor)
  - Further refined as more details of the design are implemented
- The forward capability need to be further strengthened for sufficient safety margin
  - Driving R&D towards first fully projective SPACAL
- Now, with promising progress towards 2D-tapered SPACAL
  - Implemented fully projective SPACAL design in Geant4
  - Re-evaluating performance for the pre-CDR

Extra Information

Momentum distribution of Upsilon Electrons, With thinner SPACAL + background sub. + NON-PROJECTIVE

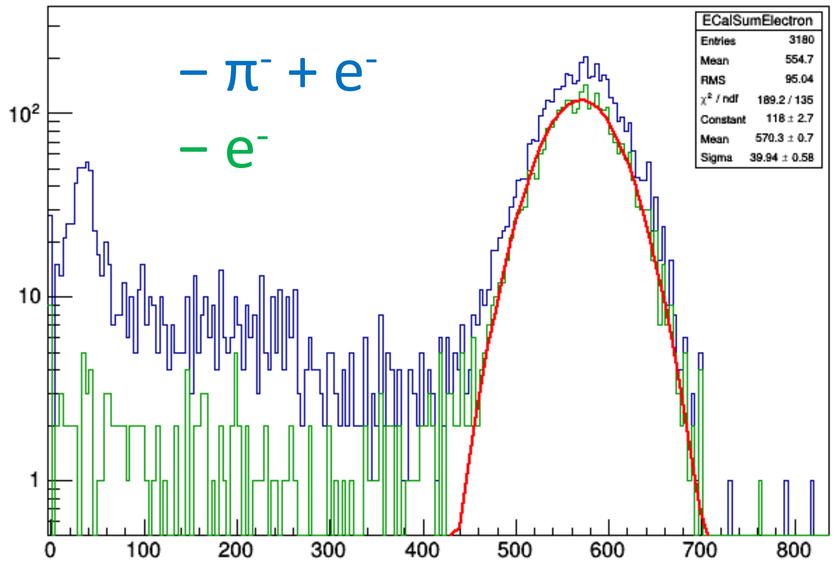




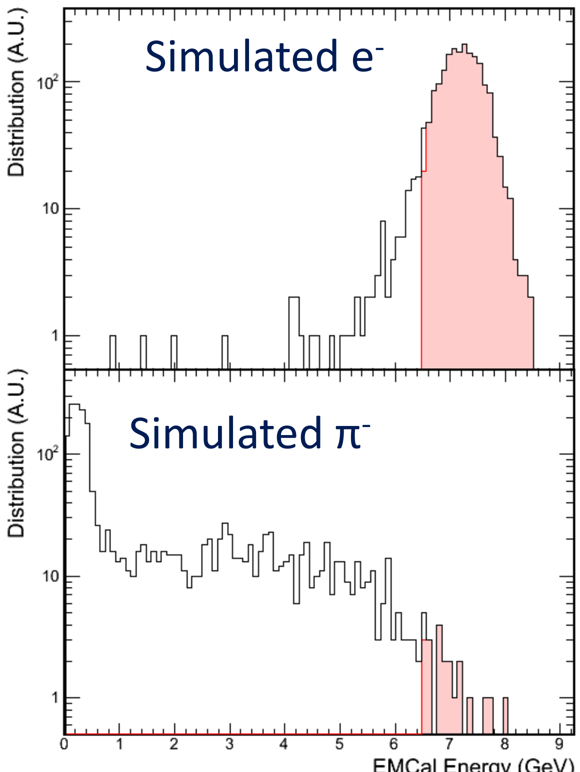
Final check should be against data

- Next steps will be quantitative check against beam test data

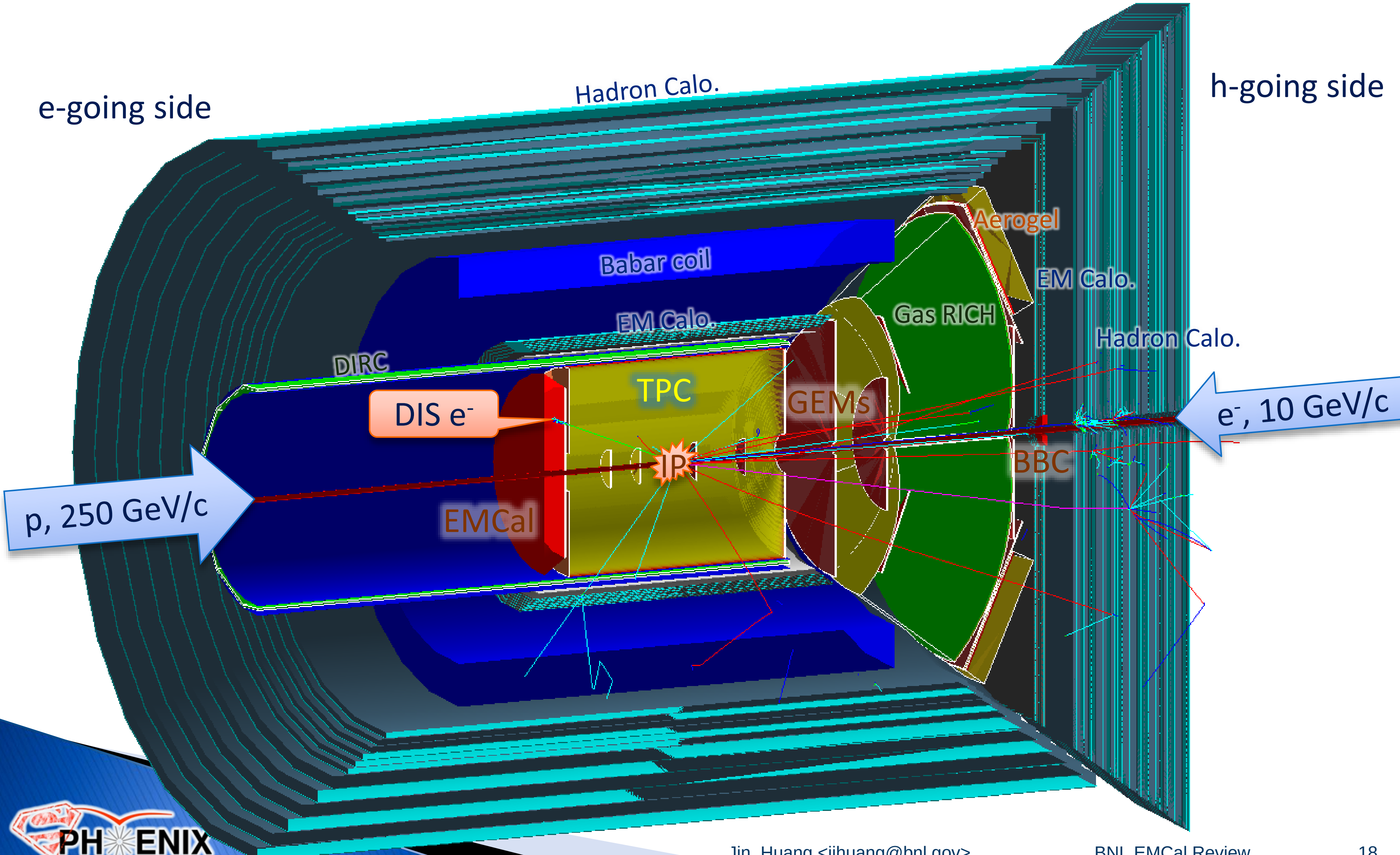
Courtesy : O. Tsai (UCLA)
SPACAL prototypes in 2014 Fermilab beam test
Energy sum for 5x5 towers
(asking for separated spectrum)



sPHENIX simulation of 8GeV e/π⁻
Energy sum for 5x5 towers
(w/o scint. light modeling)



Calorimeters in e/fsPHENIX

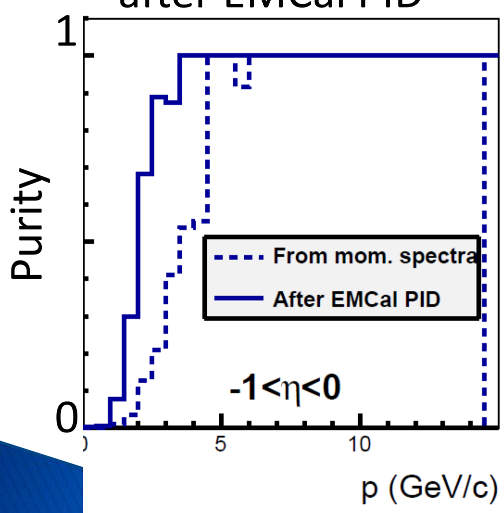


Use of calorimeter for EIC physics

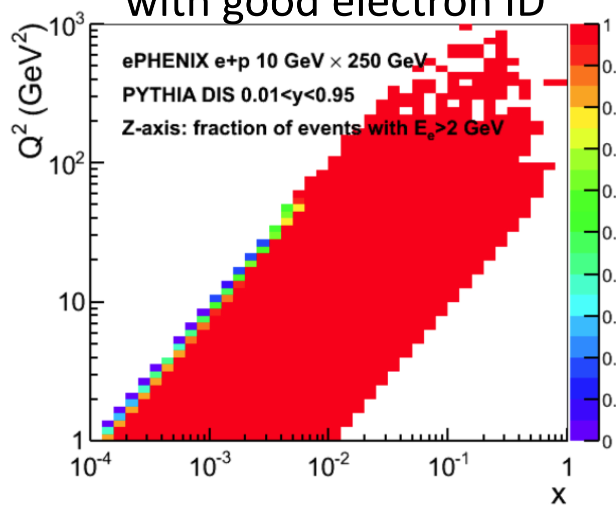
- Electron identification (e-EMC, barrel EMC)
- Electron kinematics measurement (e-EMC, barrel EMC)
- DIS kinematics using hadron final states (barrel EMC/HCal, h-EMC/HCal)
- Photon ID for DVCS (All EMC)

From Sasha and Karen using parameterized performance

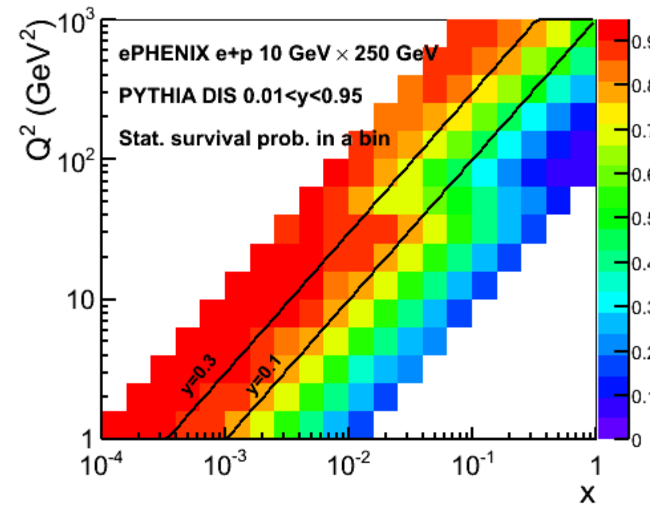
Electron purity after EMCal PID



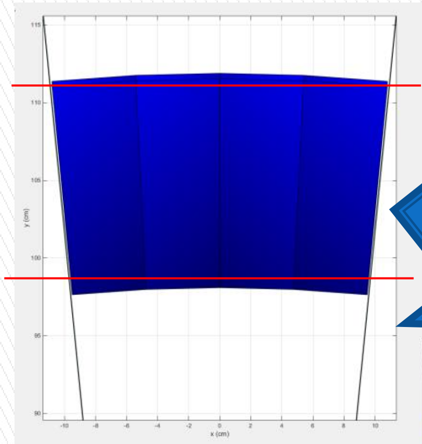
Fraction of DIS event with good electron ID



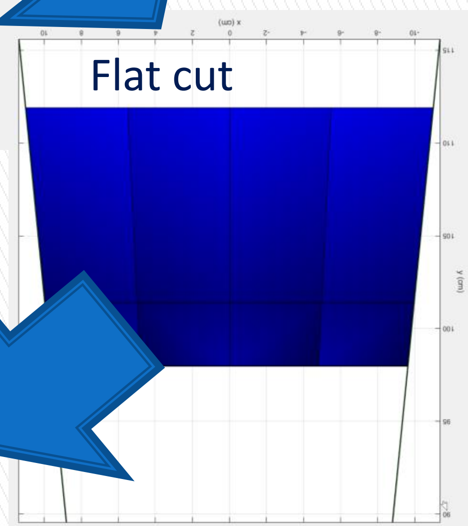
DIS kinematics survivability
Electron kinematic method



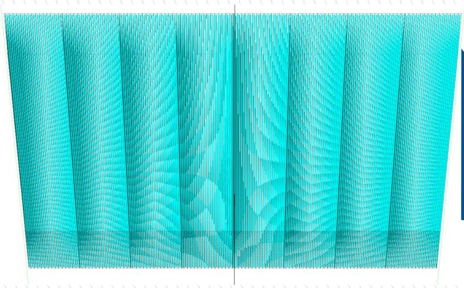
Further design and updates



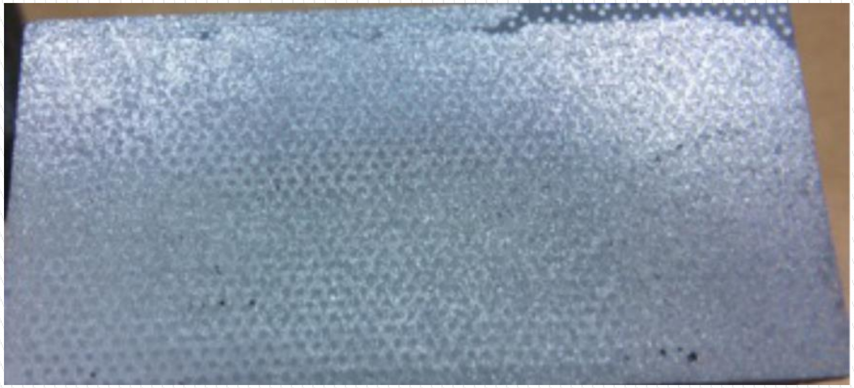
Original design

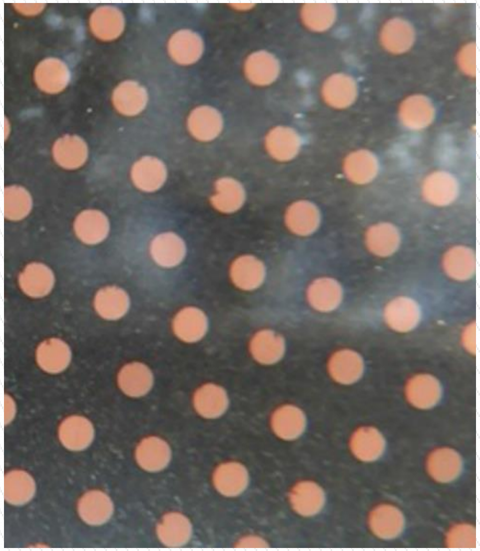


Geant4 with fiber



Build blocks to fit and machine cut top and bottom to flat

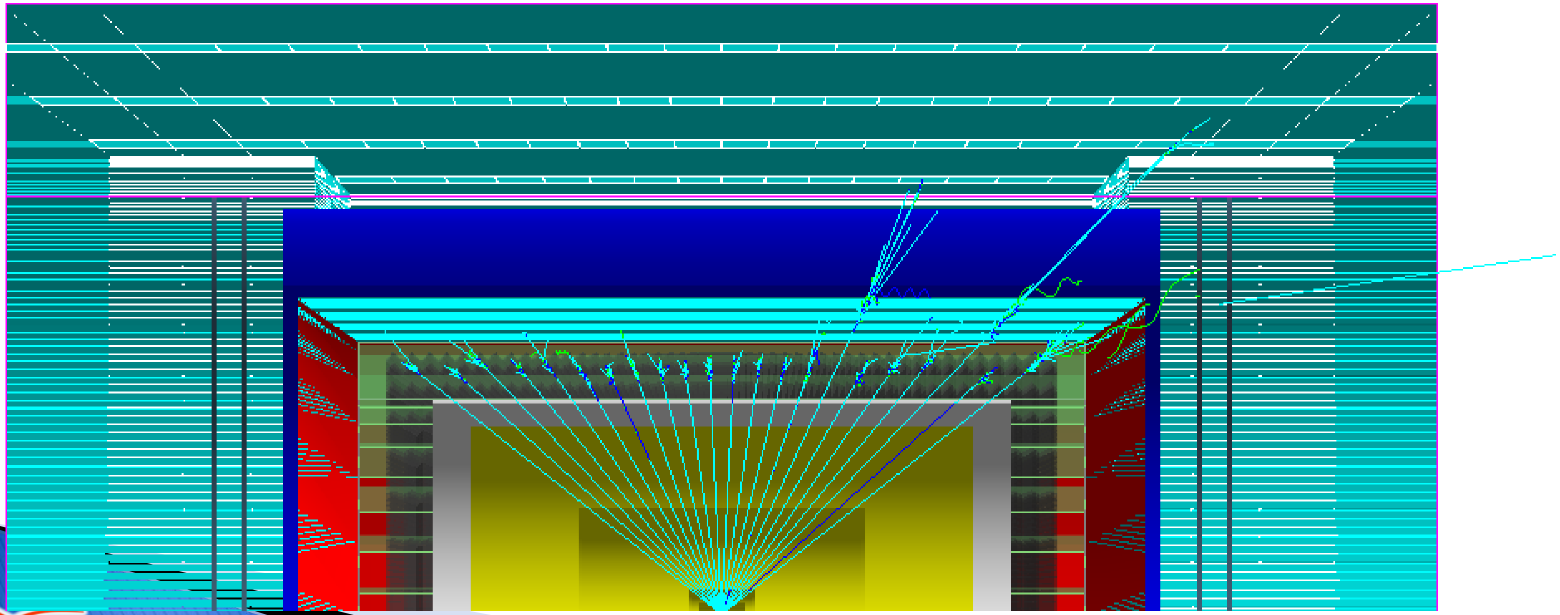




Experimental diamond cut UIUC group

Implementation in Geant4

- Enabled with new branch 2DSpacal:
  - Not in nightly build by default (currently in evaluation)
  - To use: check out from GitHub:
    - https://github.com/sPHENIX-Collaboration/coresoftware/tree/2DSpacal
    - https://github.com/sPHENIX-Collaboration/macros/tree/2DSpacal
- Currently need ~5min to run the first event due to large number of unique geometry objects. Then ~2 EM shower/min

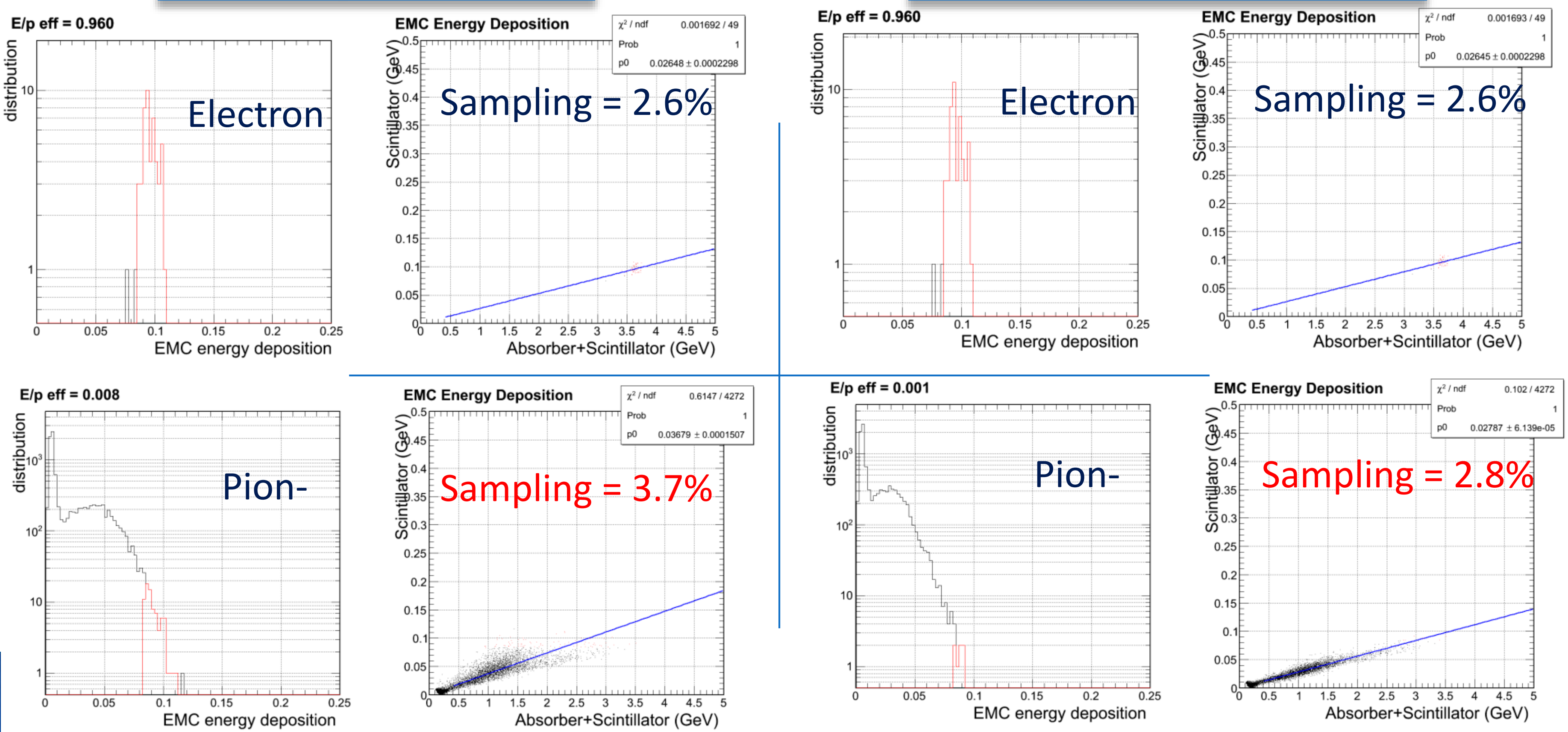


Implementing Birk's law

- Available now in G4hit level
- Could significantly affect e/h for both EMC and HCal

Sum energy deposition

With scintillation light model

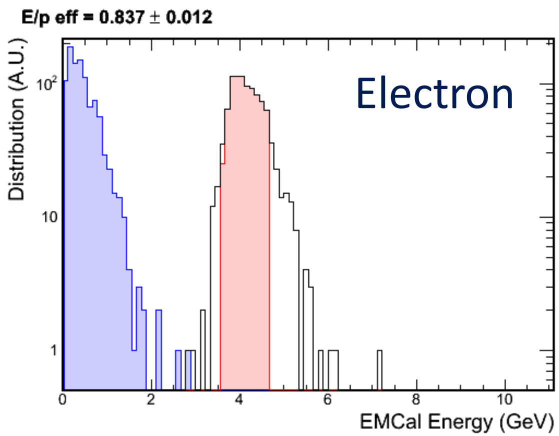


eID in central AuAu, central pseudo-rapidity

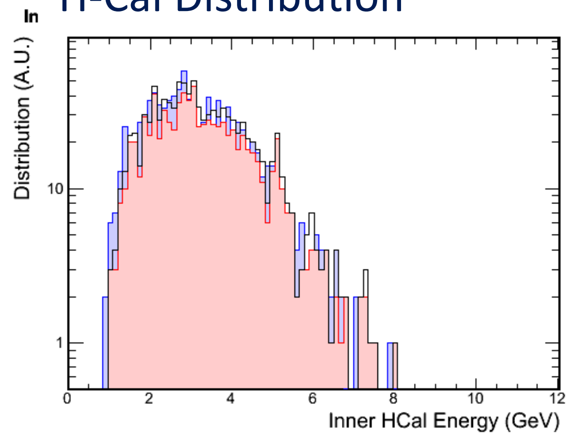
4GeV electron and pion-, $|\eta|<0.2$

EMCal tower cut : R<3cm, Hcal cut : R<20cm

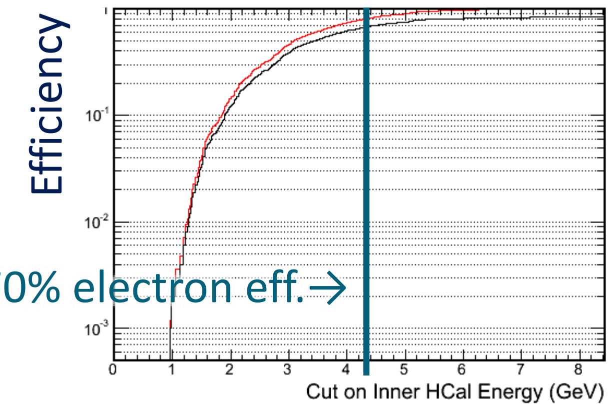
- Hijing background (AuAu 10%C in B-field)
- all c(w/ embedding)
- with EMCal E/p cut (w/ embedding)

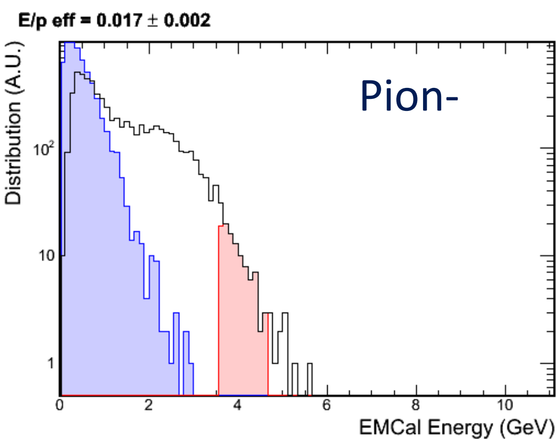


H-Cal Distribution

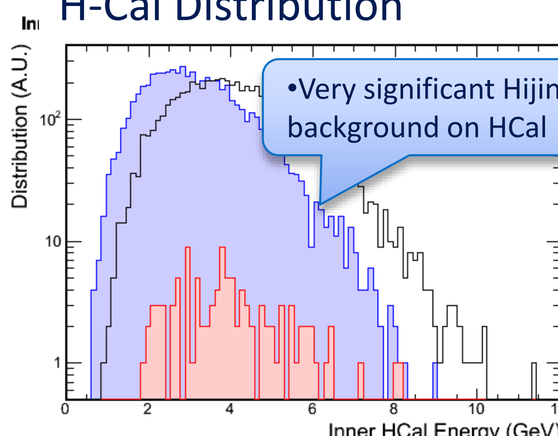


H-Cal Cut Efficiency



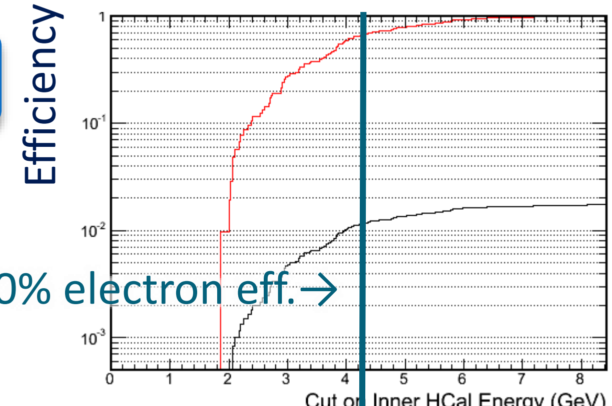


H-Cal Distribution



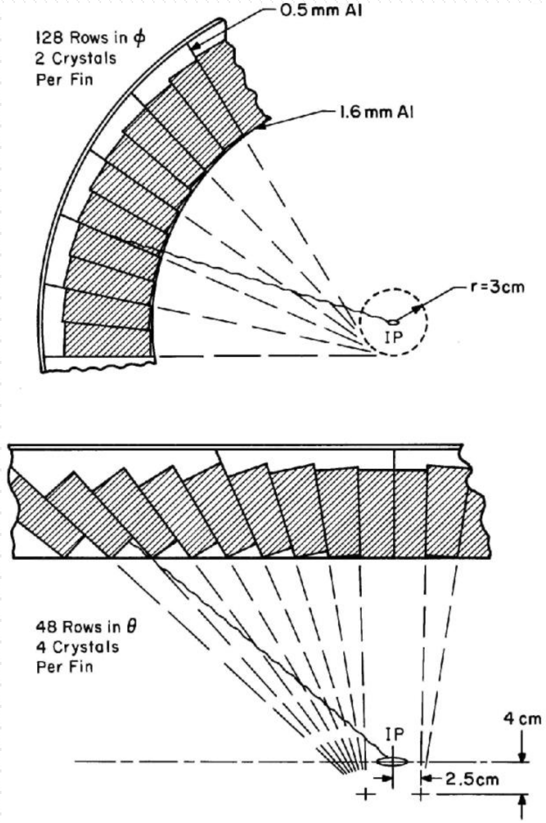
•Very significant Hijing background on HCal

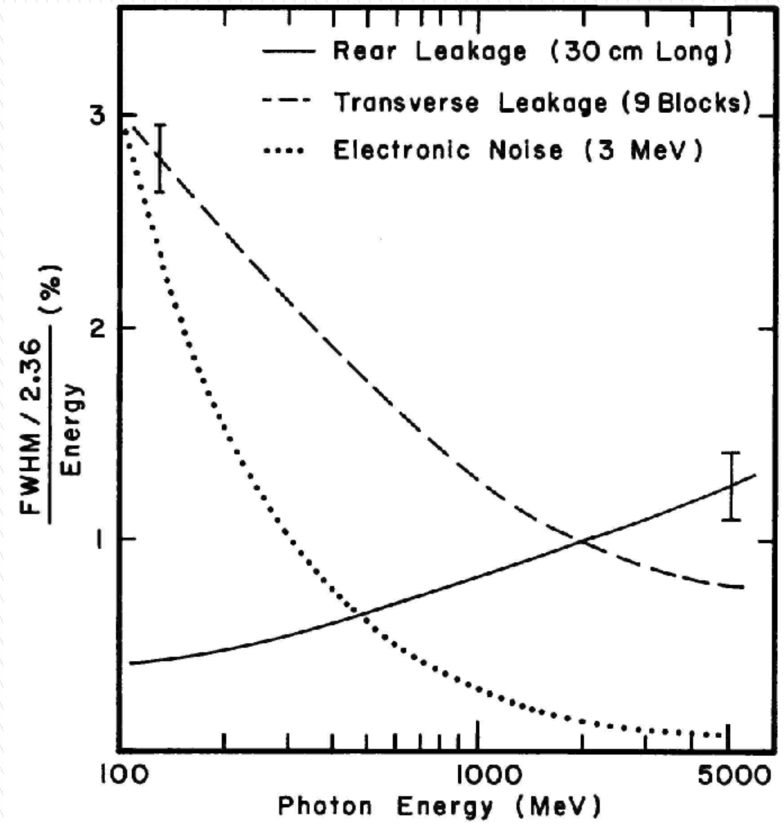
H-Cal Cut Efficiency



- Additional rejection of x2 from H-Cal
- **Total rejection ~90:1**

Cracks and steps are not new problem
See also projective crystal calorimeters





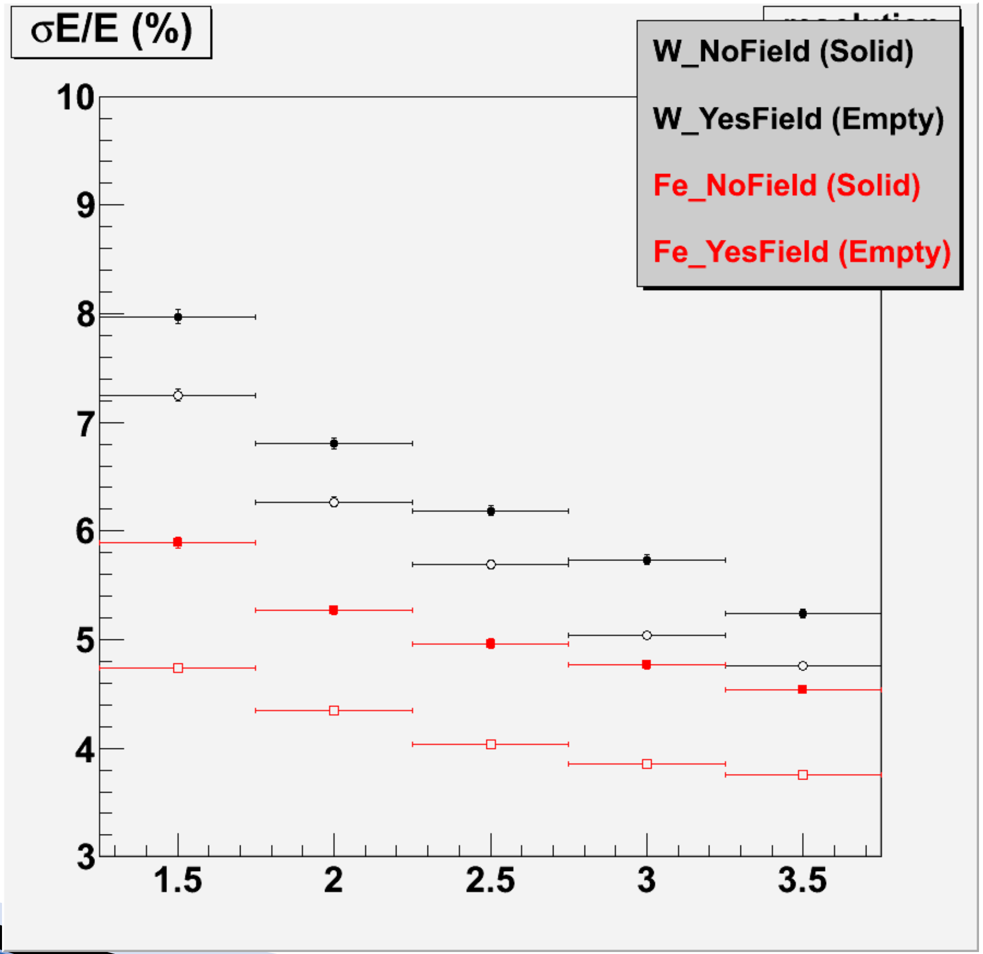
CLEO II EMCal Design

In contribution to energy resolution

Stolen from QWG3 Topical School. B Heltsley. Oct 2004

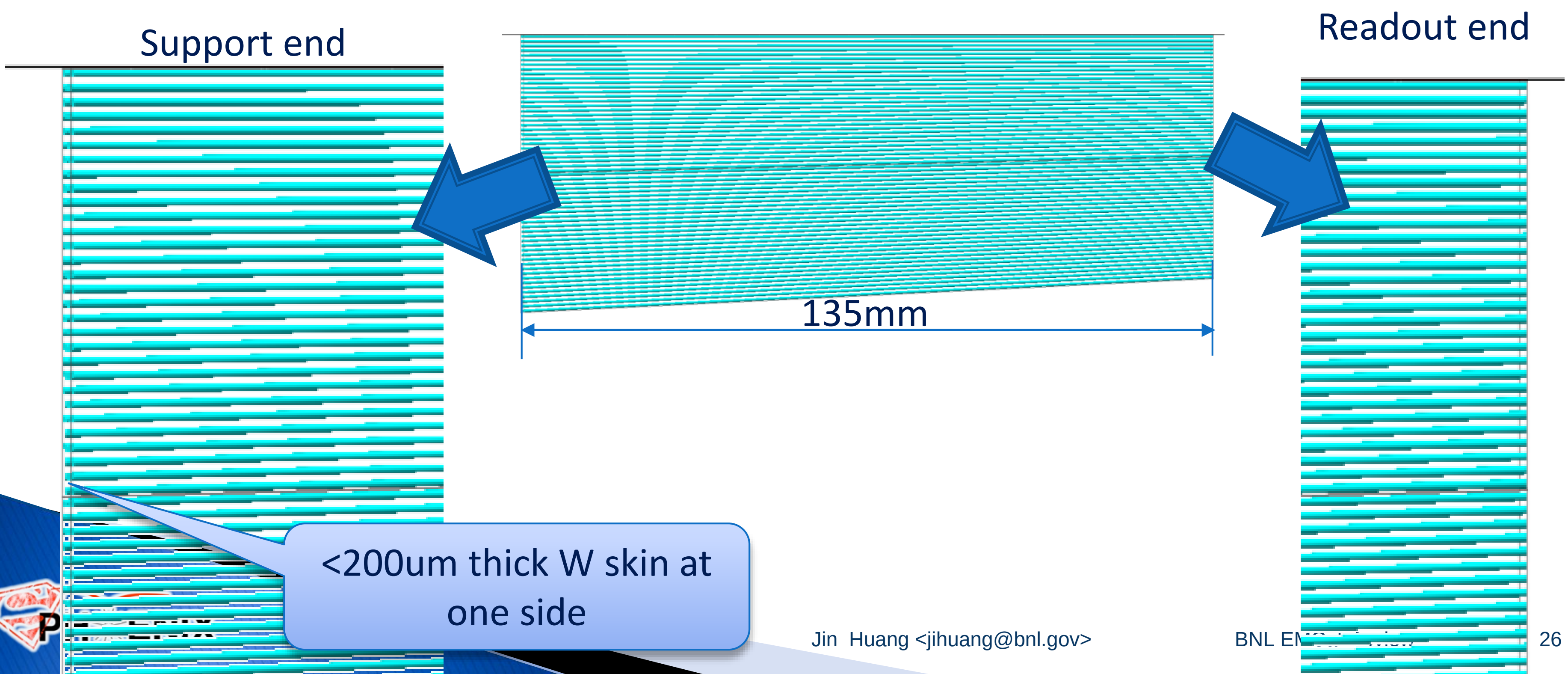
Early SoLID Shashlyk EMCal simulation

1.5 T magnetic field along direction of EM shower

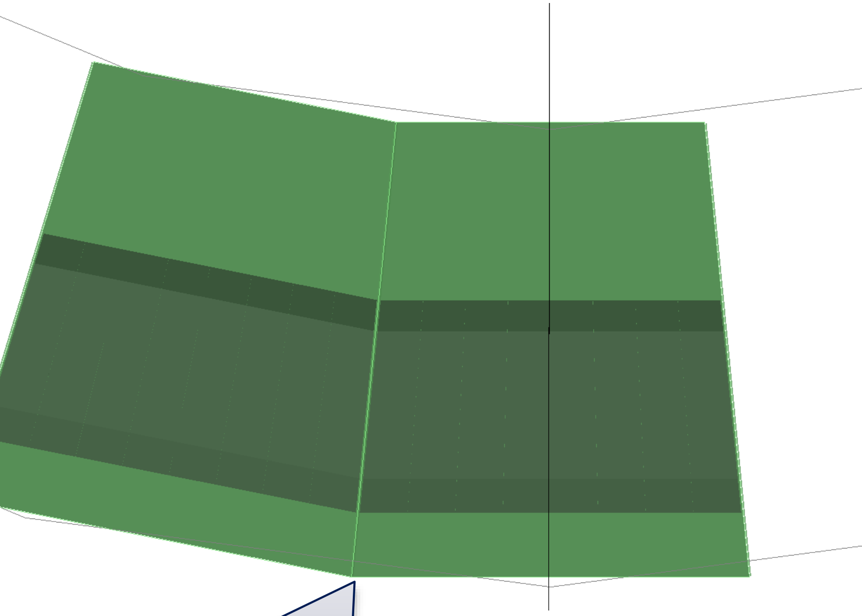


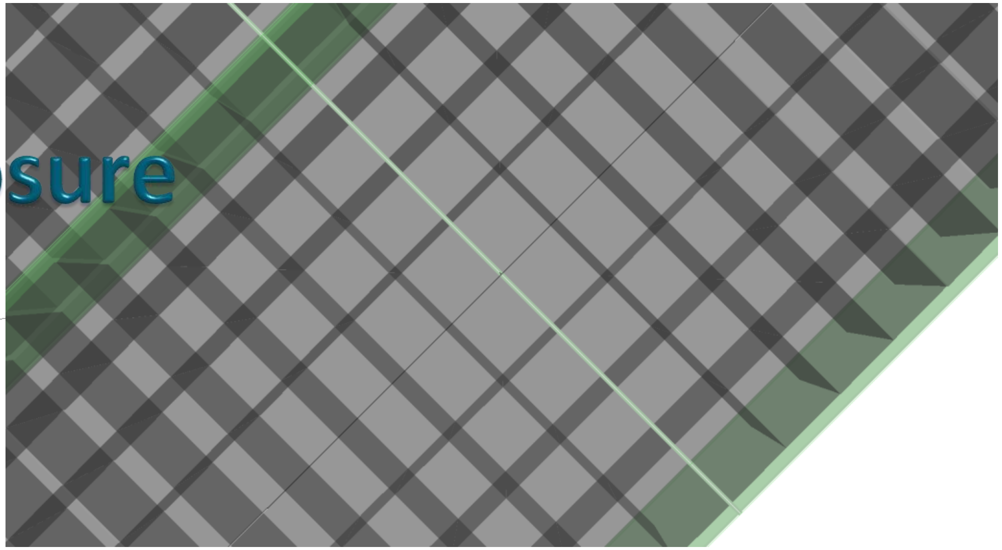
Detail view –
One trick used to speed up construction

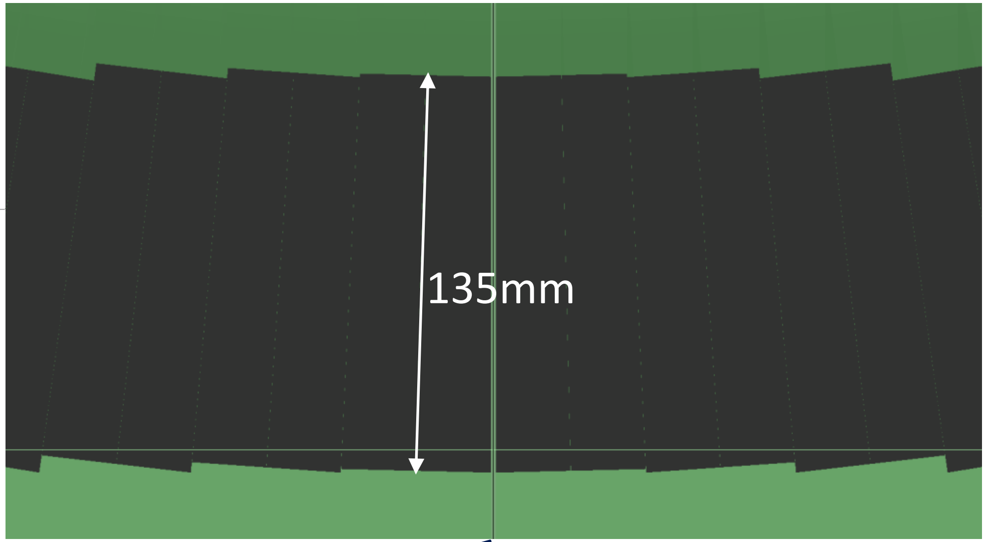
- Most fibers (~700/module) has different length in each SPACAL module (~400 unique pieces), which leads to large number of logical volume in G4, which take ~5min to construct
- Tremendously speed up by using same fiber length per module. This leave a <200um thick W skin at the end of the modules. Expect negligible impact to simulation precision.



Detail view – super module enclosure



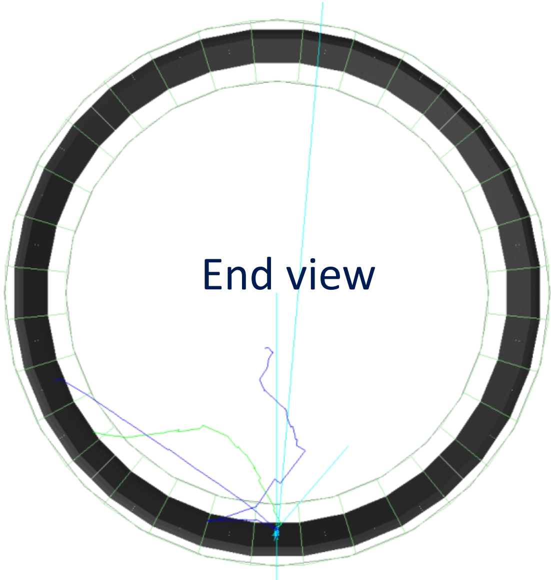


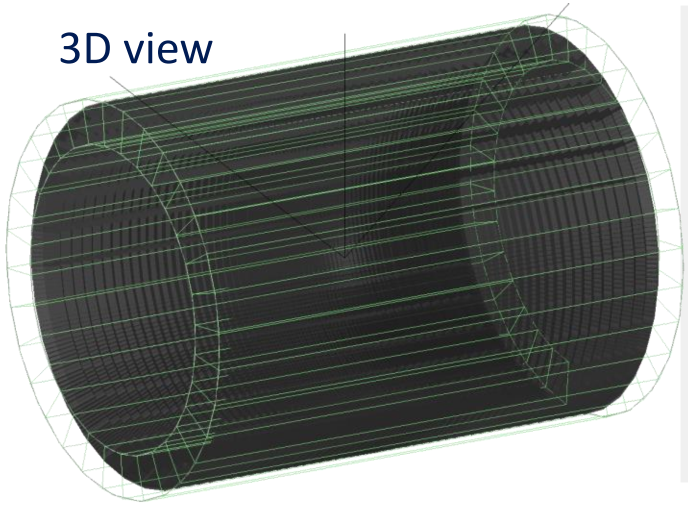


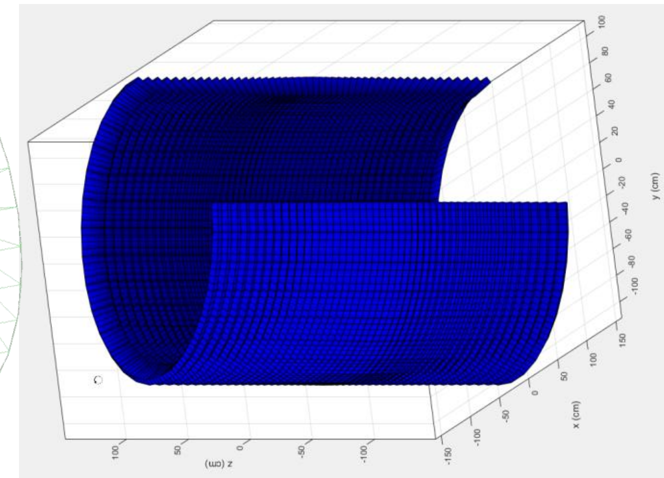
Side walls:
750um SS310 steel skin
300um tolerance outside super modules skins (gap thickness = 600um)

end walls:
750um SS310 steel skin
2mil tolerance outside super modules skins (gap thickness = 50um)

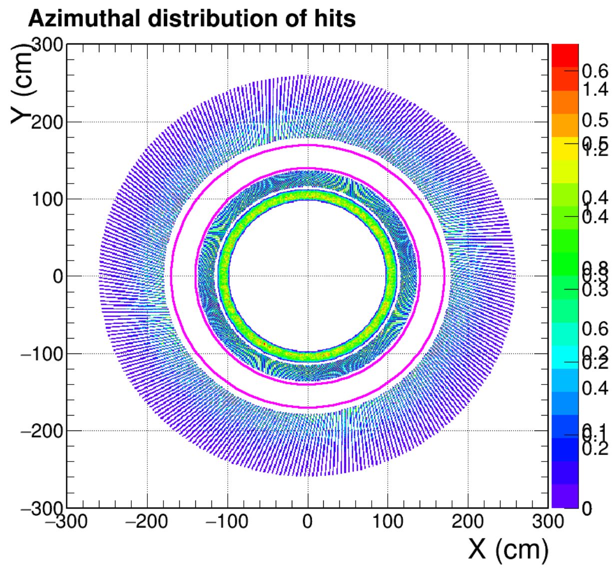
Detail view – more view

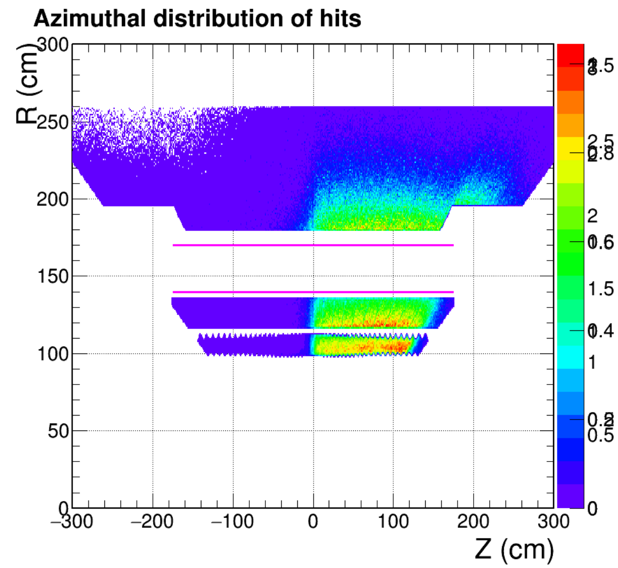




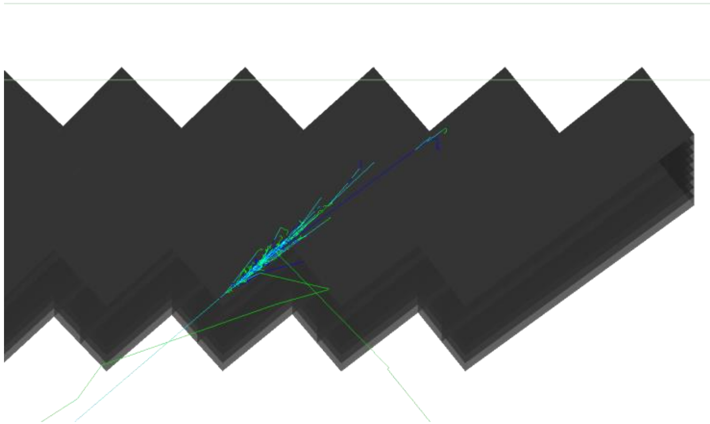


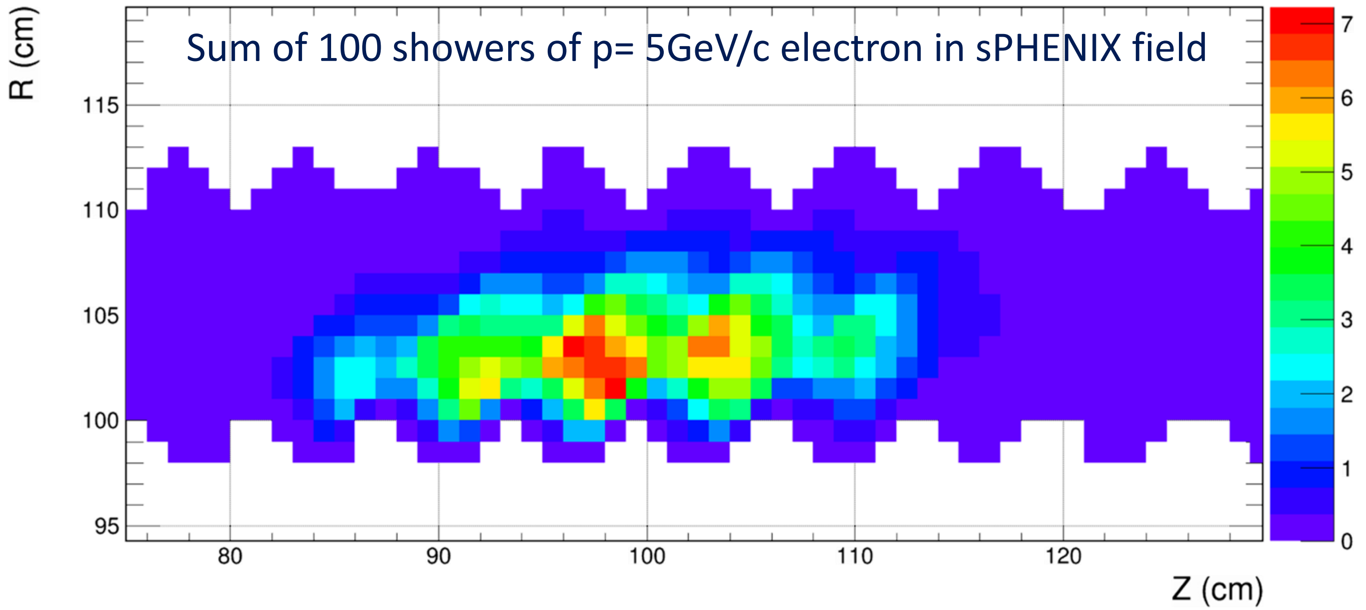
p_T = 4GeV/c negatively charged pions

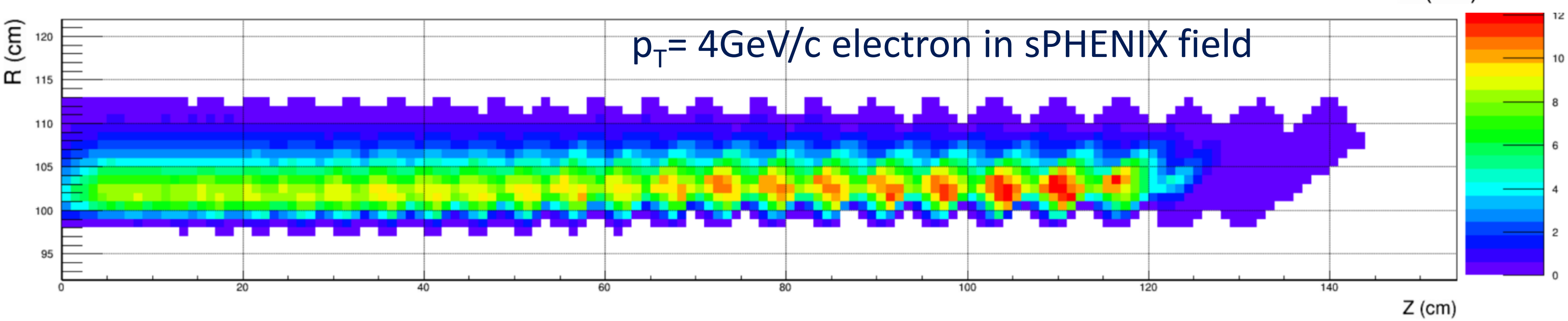




Energy distribution

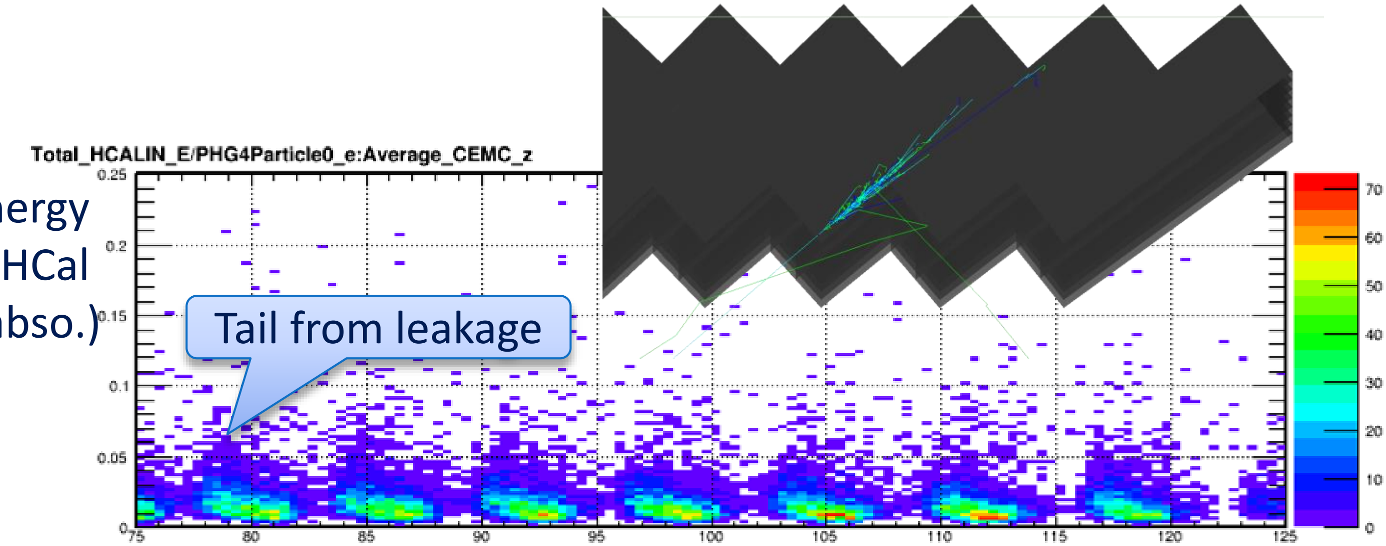






Leakage looks OK so far (vs <z>). Still in verification p_T= 4GeV/c electron in sPHENIX field

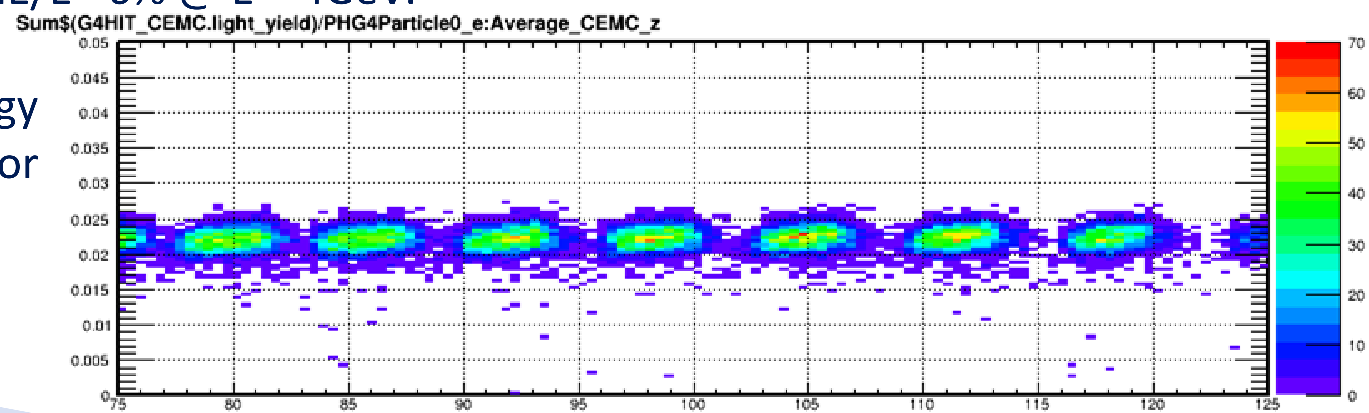
Ratio of energy in inner HCal (scint + abso.)



<z> of each shower in cm

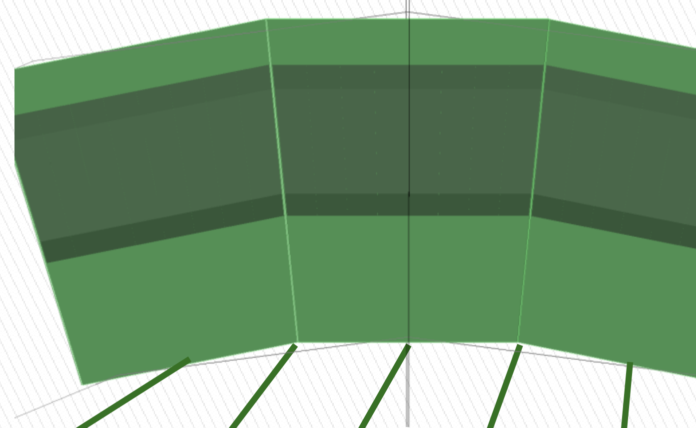
In comparison to energy resolution dE/E~ 6% @ E = 4GeV:

Ratio of energy in SPACAL scintillator



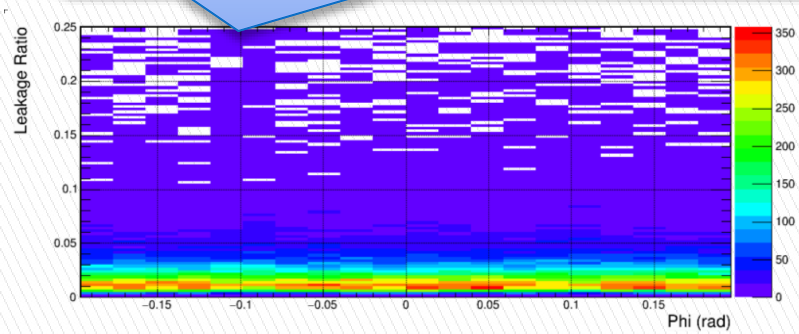
<z> of each shower in cm

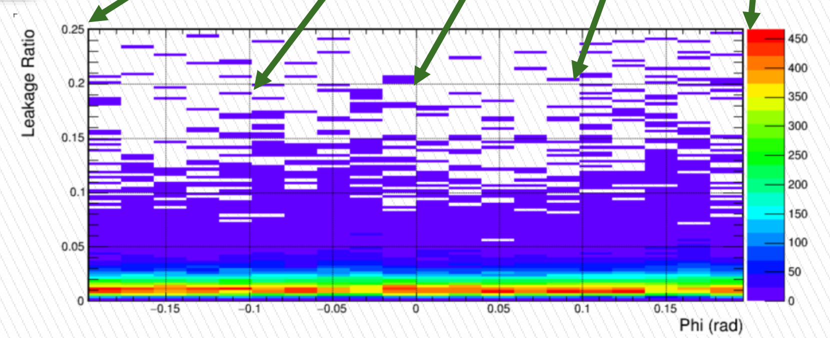
Azimuthal Leakage also not so bad
p_T= 4GeV/c particles in sPHENIX field
-5 cm < vz < 10 cm, 0<eta<1.0



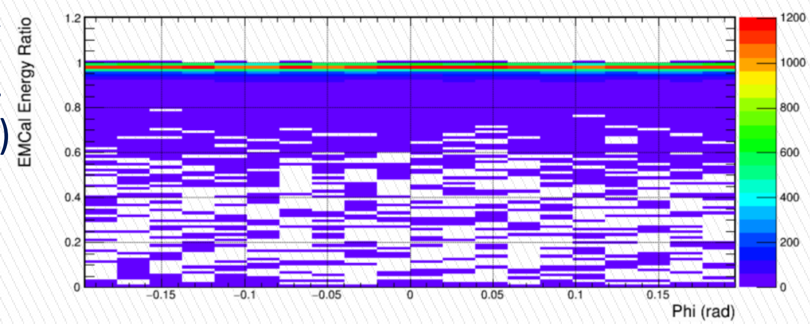
Super module edge:
600um gap over 20cm length
or ~0.3% azimuthal gap
acceptable effect: negligible (?) lower photon eff.

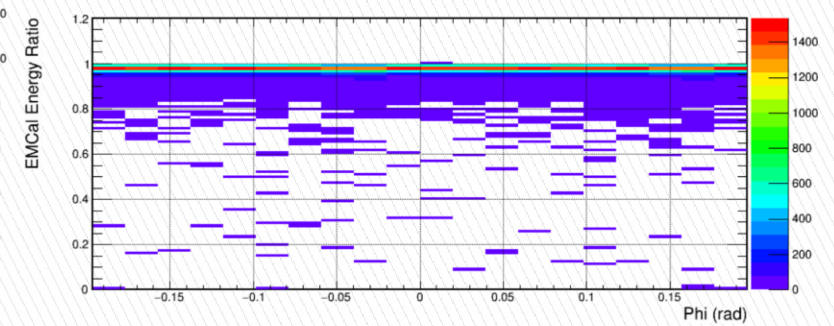
Ratio of energy in inner HCal (scint + abso.)





Ratio of energy in SPACAL (scint + abso.)



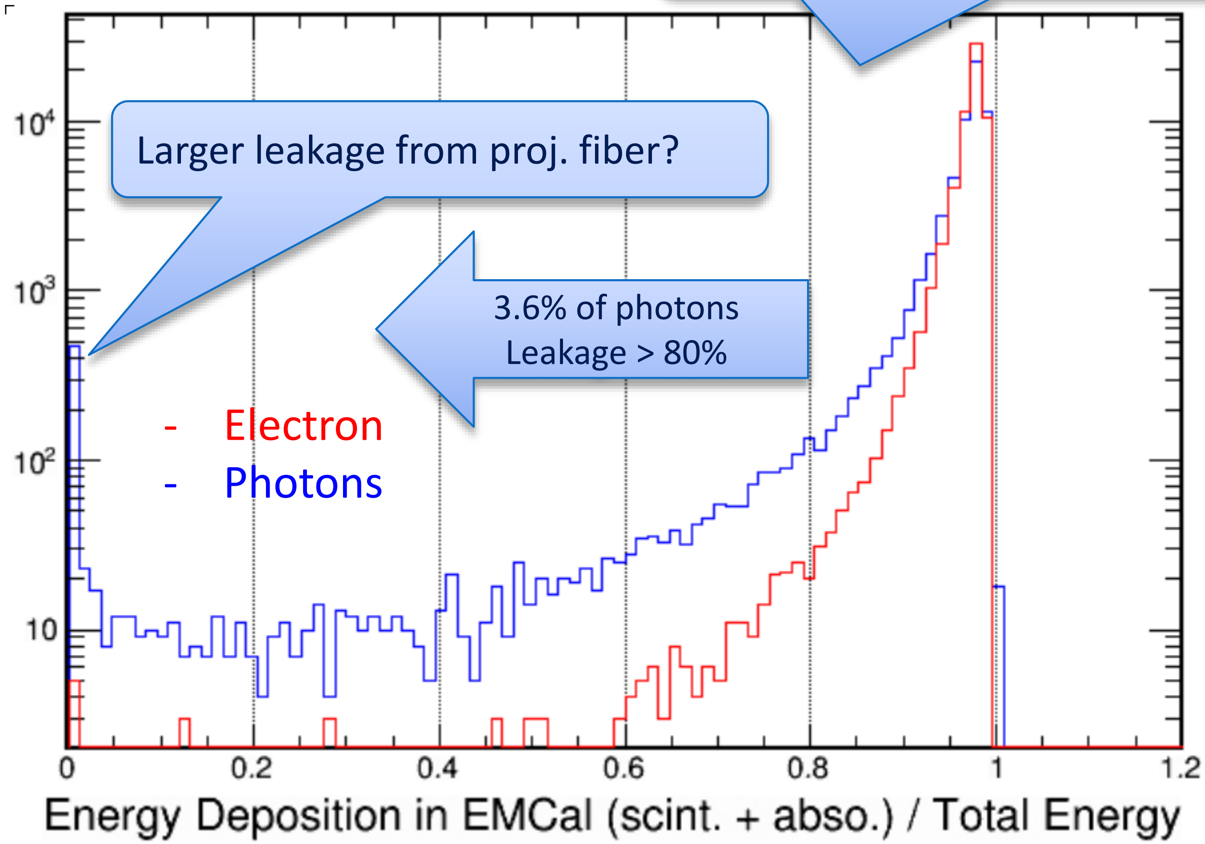


Photons

Electrons

Leakage: integrated over acceptance
p_T= 4GeV/c particles in sPHENIX field
-5 cm < vz < 10 cm, 0<eta<1

8% of photon leave 80-90% energy in EMCal
-> kinematic smearing in gamma-Jet measurements



Do we have that with realistic waving fiber?
Solution: Tilt SPACAL by 25 mrad? Inner HCal veto?

Path forward

Geant4 Implementation

- In nightly built
- (G4 default) Birk effect applied
- Need larger production sample
- Need to finish fine tune and verification of Geant4 parameters
  -- Studies --
- Quantify leakage & cracks
- Variation of sampling fraction

Digitalization

- Need some details in mapping hit to tower
- Add electronics noise
  -- Studies --
- Energy resolution
- Verify pion response VS test beam
- Uniformity VS edge/center of block/Super module, VS rapidity

Track – tower matching

- For charged tracks : extrapolate track to towers (need to tune the existing code)
- Clusterizer for photons (need new one for HI environment)
  -- Studies --
- Electron ID performance with EMCal towers + inner HCal
- Photon response
- Calibration

Final Projection

- Need Upsilon and background simulation
- Photon Jet samples
  -- Studies --
- Final di-electron candidate line shape near Upsilon peaks
- RAA projection
- Bin migration and unfolding for photons-jets